U.S. DEPARTMENT OF COMMERCE
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PB-281 303

Screening Study for Vacuum Distillation Units in Petroleum Refineries

Monsanto Research Corp, Dayton, Ohio

Prepared for

Environmental Protection Agency, Research Triangle Park, N C

Dec 76

PB 281 303

EPA-450/3-76-040
December 1976

SCREENING STUDY FOR VACUUM DISTILLATION UNITS IN PETROLEUM REFINERIES

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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TECHNICAL REPORT DATA
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1. REPORT NO. EPA-450/3-76-040	2
3. RECIPIENT'S ACCESSION NO. PB281303	
4. TITLE AND SUBTITLE: Screening Study for Vacuum Distillation Units in Petroleum Refineries	5. REPORT DATE: December 1976
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S): T. E. Ctvrtnicek, Z. S. Khan, J. L. Delaney and D. E. Earley	8. PERFORMING ORGANIZATION REPORT NO. MRC-DA-597
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Monsanto Research Corporation, 1515 Nicholas Road, Dayton, Ohio 45407	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO. 68-02-1320, Task 24
12. SPONSORING AGENCY NAME AND ADDRESS: U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Emission Standards and Engineering Division, Research Triangle Park, North Carolina 27711	13. TYPE OF REPORT AND PERIOD COVERED: Final, 3-1-76 to 6-30-76
	14. SPONSORING AGENCY CODE: 200/04

15. SUPPLEMENTARY NOTES

EPA Project Officer: Kent C. Hustvedt

16. ABSTRACT

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This report was submitted in fulfillment of Contract No. 68-02-1320, Task 24, by Monsanto Research Corporation under the sponsorship of the U. S. Environmental Protection Agency. This report covers a period from 1 March 1976 to 30 June 1976, and work was completed as of 30 June 1976.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Control Equipment Hydrocarbons Petroleum Refining Vacuum Distillation	Air Pollution Control Stationary Sources Hydrocarbon Emission Control	13 B 14 B 07 C 13 H

18. DISTRIBUTION STATEMENT: Unlimited	19 SECURITY CLASS (This Report): Unclassified	21. NO. OF PAGES: 73
	20 SECURITY CLASS (This page): Unclassified	22 PRICE

EPA Form 2220-1 (9-73)

EPA-450/3-76-040

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Contract No. 68-02-1320
Task No. 24

EPA Project Officer: Kent C. Hustvedt

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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Publication No. EPA-450/3-76-040

ABSTRACT

This program developed background information on vacuum distillation and used that information to estimate the atmospheric emission reduction expected from potential new source performance standards (NSPS) for the petroleum refining industry. The potential of available methods to reduce hydrocarbon emissions from refinery vacuum distillation units is discussed. A summary of available air pollution regulations is presented. If no new source performance standards are established, hydrocarbon emissions from vacuum distillation could increase to 12.87 - 14.50 Gg/yr by 1985. Should new performance standards go into effect, these 1985 emissions could be limited to 7.61 Gg/yr.

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ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of Exxon Research and Engineering, Florham Park, New Jersey, and Standard Oil Company of Ohio, Lima, Ohio. The assistance of Rossnagel & Associates, Inc., Cherry Hill, New Jersey, in summarizing state standards and regulations is also acknowledged.

SECTION I

INTRODUCTION

This study on vacuum distillation in the petroleum refining industry was conducted to develop basic background information and to estimate the reduction in atmospheric hydrocarbon emissions that can be achieved by implementing new source performance standards. The results of this study will be used as part of the Emission Standards and Engineering Division's assessment of numerous industries for the purpose of establishing priorities for setting standards.

A review of existing state and local air pollution regulations indicates that even the best defined and most stringent hydrocarbon emission regulations are too subjective to assure that hydrocarbon emissions from refinery vacuum distillation operations will be limited to the level achievable by application of the best available control technology.

It has been estimated that presently 83.3% (by number) of the operating refineries, which have 91.7% of the total vacuum distillation capacity, obtain complete control of hydrocarbon emissions from their vacuum distillation units. Current (1975) emissions from the vacuum distillation units (8.3% of the total vacuum distillation capacity) have been estimated to be 9.62 Gg/yr (10,622 tons/yr). If no new source performance standards are established, hydrocarbon emissions from vacuum distillation could increase to 12.87 Gg/yr (14,202 tons/yr) assuming simple growth or 14.50 Gg/yr (16,013 tons/yr) assuming compound industry growth by 1985. Should new performance standards go into effect, these emissions could be limited to 7.61 Gg/yr (8,390 tons/yr) by 1985, achieving an atmospheric hydrocarbon emission reduction of 5.26 Gg/yr (5,812 tons/yr) assuming simple growth or 6.89 Gg/yr (7,623 tons/yr) assuming compound growth.

SECTION II

CONCLUSIONS AND RECOMMENDATIONS

Vacuum distillation units used in the petroleum refining industry are closed systems under vacuum. The only source of hydrocarbon emissions to the atmosphere is the vacuum generation system. These emissions can be effectively reduced by techniques that are being practiced such as vapor recovery or disposal, or vapor absorption.

Vapor recovery has been reported to be the most commonly used method for reducing atmospheric emissions from vacuum distillation units. Noncondensable gas recovered by vapor recovery is burned in the nearest refinery boiler or heater, thus preventing atmospheric pollution while providing useful heat.

At present, state and local air pollution regulations are not specific to hydrocarbon emissions from vacuum distillation.

An estimated 83.3% of all refineries, representing 91.7% of total vacuum distillation capacity, prevent hydrocarbon emissions to the atmosphere from vacuum distillation units for safety and economic reasons. This is an indication that vapor recovery or disposal, or vapor absorption systems can be practical means for reducing hydrocarbon emissions from refinery vacuum distillation units. Essentially complete control of hydrocarbon emissions for vacuum distillation units is achievable if these available hydrocarbon emission control techniques are implemented.

The development of standards of performance could considerably reduce atmospheric hydrocarbon emissions (by 41% assuming simple growth or by 54% assuming compound industry growth) in 1985.

SECTION III

VACUUM DISTILLATION IN THE PETROLEUM INDUSTRY

A summary of petroleum refinery vacuum distillation units is presented in Table 1.[1] This table lists 172 refineries in the United States operating vacuum distillation units, and gives the location (state and city), crude processing capacity, and vacuum distillation capacity of each one. The total number of refineries in the United States as of January 1976 was 256.[1] The total capacity for vacuum distillation was 10.44 m^3/s [5.67 million barrels per day (b/sd)]. This represents 36.2% of total U.S. crude capacity. The percent of crude oil being vacuum distilled has remained constant, averaging 35.54 ± 1.3% from 1965 through 1975 (see Table 2).[1-11] Vacuum distillation capacity has been increasing at an average annual rate of 4.2% since 1965 (see Table 2). Assuming this rate

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[1]Cantrell, A. Annual refining survey. The Oil and Gas Journal, 74(13):124-156, 1976.

[2]Cantrell, A. Annual refining survey. The Oil and Gas Journal, 73(14):96-118, 1975.

[3]Cantrell, A. Annual refining survey. The Oil and Gas Journal, 72(13):82-103, 1974.

[4]Cantrell, A. Annual refining survey. The Oil and Gas Journal, 71(14):99-121, 1973.

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[9]Stormont, D. H. Annual refining survey. The Oil and Gas Journal, 66(14):130-153, 1968.

[10]Stormont, D. H. Annual refining survey. The Oil and Gas Journal, 65(14):183-203, 1967.

[11]Stormont, D. H. Annual refining survey. The Oil and Gas Journal, 64(13):152-171, 1966.

TABLE 1. U.S. REFINERIES USING VACUUM DISTILLATION UNITS[1]

State	Company	Location	Crude capacity, b/cd[a]	Crude capacity, b/sd[b]	Charge capacity, vacuum distillation, b/sd[b]
Alabama	Hunt Oil Co.	Tuscaloosa	29,000	30,000	17,500
Arizona	Arizona Fuels Corp.	Fredonia	4,000	4,211[c]	2,500
Arkansas	Cross Oil & Refining Co.	Smackover	5,850	6,000	3,100
	Lion Oil Co.	El Dorado	47,000	48,300	17,000
	Macmillan Ring-Free Oil Co.	Norphlet	4,400	4,500	3,000
California	Atlantic Richfield Co.	Carson	181,500	193,000	93,000
	Champlin Petroleum Co.	Wilmington	30,600	31,500	20,000
	Douglas Oil Co.	Paramount	46,500	48,000	28,000
		Santa Maria	9,500	10,000	7,800
	Edgington Oil Co.	Long Beach	29,500	30,000	15,000
	Exxon Co.	Benicia	88,000	97,000	54,000
	Golden Bear Division Witco Chemical Corp.	Oildale	10,500	11,000	9,500
	Gulf Oil Co.	Hercules	27,000	28,300	5,900
	Gulf Oil Co.	Sante Fe Springs	51,500	53,800	25,000
	Lunday-Thagard Oil Co.	South Gate	5,400	4,300	2,150
	Mobil Oil Corp.	Torrance	123,500	130,000	95,000
	Newhall Refining Co., Inc.	Newhall	11,500	12,105[c]	6,000
	Phillips Petroleum Co.	Martinez	110,000	115,790[c]	74,000
	Shell Oil Co.	Martinez	100,000	103,000	55,300
		Wilmington	96,000	101,000	60,000
	Standard Oil Co. of California	El Segundo	230,000	242,105[c]	103,000
		Richmond	190,000	200,000[c]	150,000
	Toscopetro Corp.	Bakersfield	39,450	40,000	19,000
	Union Oil Co. of California	Los Angeles	180,000	111,000	83,600
		Rodeo	111,000	117,000	38,500
Colorado	Continental Oil Co.	Denver	32,500	33,500	7,000
	Refinery Corp.	Commerce City	20,425[d]	21,500	3,500
Delaware	Getty Oil Co., Inc.	Delaware City	140,000	150,000	90,700
Florida	Seminole Asphalt Refining, Inc.	St. Marks	5,700[d]	6,000	3,400
Hawaii	Standard Oil Co. of California	Barbers Point	40,000	42,105[c]	15,000
Illinois	Amoco Oil Co.	Wood River	105,000	107,000	40,000
	Clark Oil & Refining Corp.	Blue Island	66,500[d]	70,000	27,000
		Hartford	42,750[d]	45,000	18,000
	Marathon Oil Co.	Robinson	195,000	205,000	62,000
	Mobil Oil Corp.	Joliet	175,000	186,000	82,000
	Shell Oil Co.	Wood River	283,000	295,000	95,500
	Texaco, Inc.	Lawrenceville	84,000	88,421[c]	24,000
		Lockport	72,000	97,789[c]	14,000
	Union Oil Co. of California	Lemont	150,000	157,895[c]	55,000
	Yetter Oil Co.	Colmar	1,000	1,053[c]	1,000
Indiana	Amoco Oil Co.	Whiting	360,000	375,000	167,000
	Atlantic Richfield Co.	East Chicago	126,000	140,000	70,000
	Indiana Farm Bureau Coop. Association, Inc.	Mt. Vernon	18,500	20,000	7,000
	Laketon Asphalt Refining, Inc.	Laketon	8,075[d]	8,500	6,000
	Rock Island Refining Corp.	Indianapolis	32,000	33,000	17,000
Kansas	American Petrofina, Inc.	El Dorado	25,000	26,316[c]	8,000
	Apco Oil Corp.	Arkansas City	46,230	47,200	12,750
	CRA, Inc.	Coffeyville	48,000	50,000	14,500
		Phillipsburg	25,000	26,000	9,000
	Derby Refining Co.	Wichita	26,500	27,650	8,800
	Mid America Refinery Co.	Chaute	3,100	3,300	1,800
	Mobil Oil Corp.	Augusta	50,000	52,000	18,300
	National Cooperative Refinery Association	McPherson	54,150	57,000	18,000
	North American Petroleum Corp.	Shallow Water	9,500[d]	10,000	5,500
	Phillips Petroleum Co.	Kansas City	85,000	89,474[c]	15,000
	Skelly Oil Co.	El Dorado	78,700	80,000	27,000
Kentucky	Ashland Petroleum Co.	Catlettsburg	135,800	140,000	55,000
	Louisville Refining, Division of Ashland Oil, Inc.	Louisville	25,200	26,000	13,000

(continued)

TABLE 1. (continued)

State	Company	Location	Crude capacity, b/cd[a]	Crude capacity, b/sd[b]	Charge capacity, vacuum distillation, b/sd[b]
Louisiana	Atlas Processing Co., Division of Pennzoil	Shreveport	45,000	47,368[c]	600
	Bayou State Oil Corp.	Houston	3,500	4,000	2,000
	Calumet Refining Co.	Princeton	2,280[d]	2,400	2,400
	Cities Service Oil Co.	Lake Charles	268,000	280,000	83,000
	Continental Oil Co.	Lake Charles	83,000	85,000	8,000
	Exxon Co.	Baton Rouge	455,000	475,000	165,000
	Good Hope Refineries, Inc.	Metairie	42,275[d]	44,500	10,000
	Gulf Oil Co. - Alliance Refineries	Belle Chasse	180,400	186,000	67,000
	Murphy Oil Corp.	Meraux	92,50	95,400	14,500
	Shell Oil Co.	Norco	240,000	250,000	90,000
	Tenneco Oil Co.	Chalmette	95,000[d]	100,000	23,000
	Texaco, Inc.	Convent	140,000	147,368[c]	35,000
Maryland	Chevron Asphalt Co.	Baltimore	13,500	14,211[c]	13,800
Michigan	Marathon Oil Co.	Detroit	65,000	67,000	25,000
	Total Leonard, Inc.	Alma	40,000	43,000	17,000
Minnesota	Continental Oil Co.	Wrenshall	23,500	24,000	9,000
	Koch Refining Co.	Pine Bend	127,300	131,905	90,000
	Northwestern Refining Co., Division of Ashland Oil, Inc.	St. Paul Park	66,000	68,000	38,000
Mississippi	Southland Oil Co.	Sandersville	11,000	11,579[c]	5,500
		Yazoo City	4,200	4,421[c]	2,500
	Standard Oil Co. of Kentucky	Pascagoula	280,000	294,737[c]	148,000
Missouri	Amoco Oil Co.	Sugar Creek	107,000	108,000	40,000
Montana	Big West Oil Co.	Kevin	5,123	5,500	750
	Cenex	Laurel	40,400	42,500	14,000
	Continental Oil Co.	Billings	52,500	56,000	14,500
	Exxon Co.	Billings	45,000	46,000	18,000
	Phillips Petroleum Co.	Great Falls	6,000	6,316[c]	2,000
Nebraska	CRA, Inc.	Scottsbluff	5,000	5,500	2,400
New Jersey	Chevron Oil Co.	Perth Amboy	88,000	92,632[c]	50,000
	Exxon Co.	Linden	265,000	277,000	143,000
	Mobil Oil Corp.	Paulsboro	98,000	100,500	62,600
	Texaco, Inc.	Westville	88,000	92,632	29,500
New Mexico	Navajo Refining Co.	Artesia	29,930	28,434[c]	4,500
	Shell Oil Co.	Ciniza	18,000	19,000	7,900
New York	Ashland Petroleum Co.	Tonawanda	68,385	70,500	25,000
	Mobil Oil Corp.	Buffalo	43,000	44,000	18,000
Ohio	Ashland Petroleum Co.	Canton	64,000	66,000	33,000
		Findlay	20,370	21,000	8,000
	Gulf Oil Co.	Cleves	42,100	43,500	13,000
		Toledo	50,300	51,000	12,500
	Standard Oil Co. of Ohio	Lima	168,000	177,000	51,000
		Toledo	120,000	126,000	68,000
	Sun Oil Co. of Pennsylvania	Toledo	125,000	130,000	22,000
Oklahoma	Allied Materials Corp.	Stroud	5,225[d]	5,500	5,500
	Apco Oil Corp.	Cyril	14,000	14,274	4,400
	Chaplin Petroleum Co.	Enid	53,800	56,000	18,000
	Continental Oil Co.	Ponca City	126,000	131,000	32,000
	Kerr-McGee Corp.	Wynnewood	50,000	51,500	10,000
	Midland Cooperatives, Inc.	Cushing	19,000	19,814	7,000
	OKC Refining, Inc.	Okmulgee	25,000	24,000	3,200
	Sun Oil Co.	Duncan	48,500	50,000	17,000
		Tulsa	88,500	90,000	31,500
	Texaco, Inc.	West Tulsa	50,000	52,632[c]	14,500
	Wickers Petroleum Corp.	Ardmore	61,000	60,000	30,000
Oregon	Standard Oil Co. of California	Portland	14,000	14,737[c]	15,000
Pennsylvania	Atlantic Richfield Co.	Philadelphia	185,000	195,000	106,000
	BP Oil Corp.	Marcus Hook	143,000	150,000	60,000
	Gulf Oil Co.	Philadelphia	174,300	180,000	65,000
	Pennzoil Co., Wolf's Head Division	Rouseville	10,000	10,400	3,328
	Quaker State Oil Refining Corp.	Emlenton	3,320	3,495	1,700
		Farmers Valley	6,500	6,800	2,750
	Sun Oil Co.	Marcus Hook	165,000	180,000	48,000
	United Refining Co.	Warren	52,000	52,000	38,000
	Valvoline Oil Co., Division of Ashland Oil, Inc.	Freedom	6,800	7,000	3,600

(continued)

TABLE 1. (continued)

State	Company	Location	Crude capacity, b/cd[a]	Crude capacity, b/sd[b]	Charge capacity, vacuum distillation, b/sd[b]
Tennessee	Delta Refining Co.	Memphis	43,900	44,800	15,000
Texas	American Petrofina, Inc.	Mt. Pleasant	26,000	27,368[c]	15,000
		Port Arthur	84,000	88,421[c]	28,000
	Amoco Oil Co.	Texas City	333,000	347,000	164,000
	Atlantic Richfield Co.	Houston	213,000	233,500	70,000
	Champlin Petroleum Co.	Corpus Christi	67,700	68,800	10,000
	Charter International Oil Co.	Houston	64,000	70,000	22,000
	Chevron Oil Co.	El Paso	71,000	74,737[c]	24,000
	Coastal State Petrochemical Co.	Corpus Christi	185,000	194,737[c]	45,000
	Cosden Oil & Chemical Co.	Big Spring	65,000	68,421[c]	25,000
	Crown Central Petroleum Corp.	Houston	100,000	103,000	38,000
	Diamond Shamrock Oil & Gas Co.	Sunray	51,500	53,500	16,500
	Exxon Co.	Baytown	390,000	405,000	180,000
	Gulf Oil Co.	Port Arthur	312,100	319,000	147,400
	Marathon Oil Co.	Texas City	64,000	66,000	20,000
	Mobil Oil Corp.	Beaumont	325,000	335,000	103,000
		Sweeny	85,000	89,474[c]	17,000
	Shell Oil Co.	Deer Park	294,000	305,000	125,000
		Odessa	32,000	34,000	10,000
	Southwestern Refining Co., Inc.	Corpus Christi	120,000	124,000	24,000
	Suntide Refining Co.	Corpus Christi	57,000	60,000	10,000
		Port Arthur	406,000	427,368[c]	142,000
		Port Neches	47,000	49,474[c]	26,000
	Texas City Refining, Inc.	Texas City	76,500	80,000	27,500
	Three Rivers Refining, Inc.	Three Rivers	4,750[d]	5,000	3,000
	Union Oil Co. of California	Nederland	120,000	126,316[c]	43,000
	Winston Refining Co.	Fort Worth	20,000	20,500	3,500
Utah	Caribou Four Corners, Inc.	Woods Cross	5,000	5,500	1,000
	Chevron Oil Co.	Salt Lake City	45,000	47,368[c]	35,500
	Husky Oil Co.	North Salt Lake	23,000	24,000	3,800
	Phillips Petroleum Co.	Woods Cross	23,000	24,211[c]	3,000
	Western Refining Co.	Woods Cross	10,000	10,000	750
Virginia	Amoco Oil Co.	Yorktown	53,000	55,000	28,000
Washington	Atlantic Richfield Co.	Cherry Point	96,000	100,000	55,000
		Ferndale	71,500	75,000	7,000
	Mobil Oil Corp.	Anacostes	91,000	94,000	33,000
	Shell Oil Co.	Tacoma	4,500	4,737[c]	4,500
	Sound Refining, Inc.	Richmond Beach	4,500	4,737[c]	5,000
	Standard Oil Co. of California	Anacortes	78,000	82,105[c]	25,000
	Texaco, Inc.	Tacoma	21,400	22,526[c]	4,800
	U.S. Oil & Refining Co.				
West Virginia	Pennzoil Co., Elk Refining Division	Falling Rock	4,900	5,200	2,500
	Quaker State Oil Refining Corp.	Newell	9,700	10,000	4,000
		St. Marys	4,850	5,000	2,175
Wisconsin	Murphy Oil Corp.	Superior	45,400	46,800	15,500
Wyoming	Amoco Oil Co.	Casper	43,000	44,500	13,800
	Husky Oil Co.	Cheyenne	23,600	24,600	14,000
		Cody	10,800	11,300	6,500
	Little America Refining Co.	Casper	24,500	25,789[c]	5,800
	Pasco, Inc.	Sinclair	49,000	50,000	16,100
	Texaco, Inc.	Casper	21,000	22,105	10,000

[a]Calendar-day figures reported are refiner's averages for how many barrels each day a refinery unit yields on the average, including downtime used for turnarounds. These figures are what refiners actually run in a year, divided by 365.

[b]Stream-day figures represent the potential a refinery unit can yield when running full capacity.

[c]Few companies reported only calendar-day figures. To keep consistent stream-day totals, calendar-day figures were converted to a stream-day basis, using a 0.95 factor for crude and vacuum units.

[d]If companies reported only stream-day figures, calendar-day figures were obtained using a 0.95 factor for crude vacuum units.

TABLE 2. U.S. TOTAL CRUDE AND VACUUM DISTILLATION CAPACITY[1-11]

Year	Crude capacity, m^3/s (b/sd)	Vacuum distillation capacity, m^3/s (b/sd)	Percent of crude vacuum distilled[a]	Percent increase in vacuum distillation capacity[b]
1975[1]	28.9 (15,687,321)	10.4 (5,672,893)	36.2	3.2
1974[2]	28.5 (15,463,650)	10.1 (5,497,143)	35.6	3.7
1973[3]	27.4 (14,876,050)	9.75 (5,300,006)	35.6	2.9
1972[4]	25.8 (13,991,580)	9.48 (5,150,703)	36.8	6.2
1971[5]	25.2 (13,709,442)	8.93 (4,852,005)	35.4	2.3
1970[6]	24.4 (12,284,985)	8.72 (4,740,918)	35.7	4.3
1969[7]	23.3 (12,651,375)	8.37 (4,546,680)	35.9	10.4
1968[8]	22.2 (12,079,201)	7.58 (4,119,048)	34.1	0.8
1967[9]	21.5 (11,657,975)	7.52 (4,084,985)	35.0	5.1
1966[10]	20.2 (10,952,495)	7.15 (3,886,585)	35.5	3.3
1965[11]	19.7 (10,721,550)	6.92 (3,762,745)	35.1	---

[a]Average percent of crude feed vacuum distilled is 35.54 ± 1.3%.

[b]Average percent increase was determined to be 4.2 ± 44%.

of increase will remain constant through 1985, vacuum distillation capacity in 1985 will be 13.96 m^3/s (7.6×10^6 b/sd) assuming simple growth or 15.75 m^3/s (8.6×10^6 b/sd) assuming compound industry growth. This is also illustrated in Figure 1.

Table 3[1-21] lists the total number of refineries in operation as well as the number of refineries using vacuum distillation during the period from 1965 through 1975. The data from Table 3 were used to plot the graphs in Figure 2, which show that the number of refineries operating vacuum distillation units ranged between a minimum of 162 in 1970 and a maximum of 178 in 1971. During the same period, the total number of refineries ranged from a minimum of 250 in 1971 to a maximum of 270 in 1967. Based on these data, it can be concluded that during the past 10 years, the number of refineries using vacuum distillation, and the percent of operating

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[12]Mineral Industry Surveys. Pertroleum Refineries in the United States and Puerto Rico, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1975. 17 pp.

[13]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1974, 21 pp.

[14]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1973. 15 pp.

[15]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1972. 15 pp.

[16]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1971. 15 pp.

[17]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1970. 15 pp.

[18]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1969, 15 pp.

[19]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1968. 15 pp.

[20]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1967. 13 pp.

[21]Mineral Industry Surveys. Petroleum Refineries in the United States and Puerto Rico. U.S. Department of the Interior, Bureau of Mines, Washington, D.C., January 1, 1966. 11 pp.

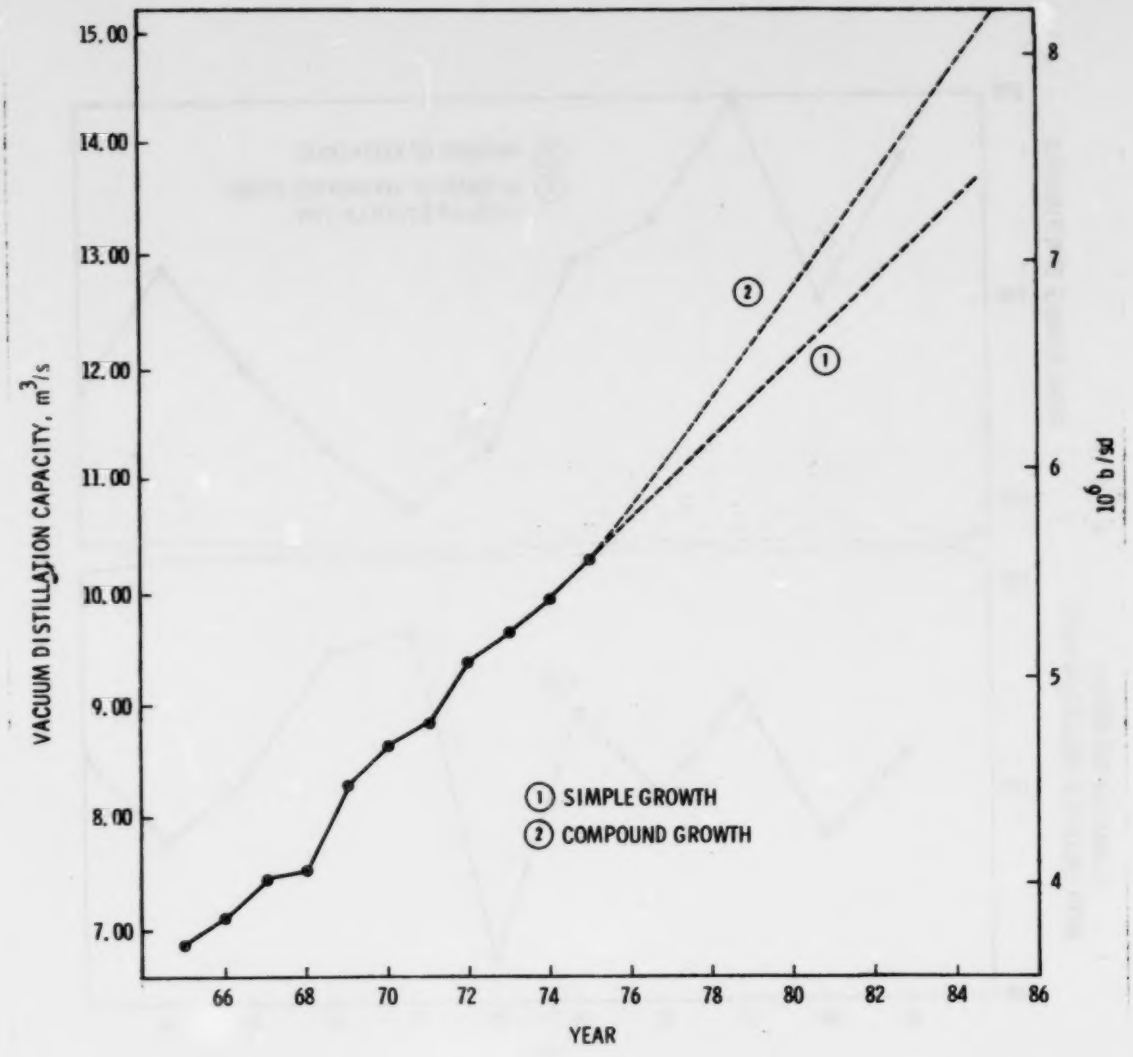

Figure 1. Vacuum distillation capacity, 1965-1985.

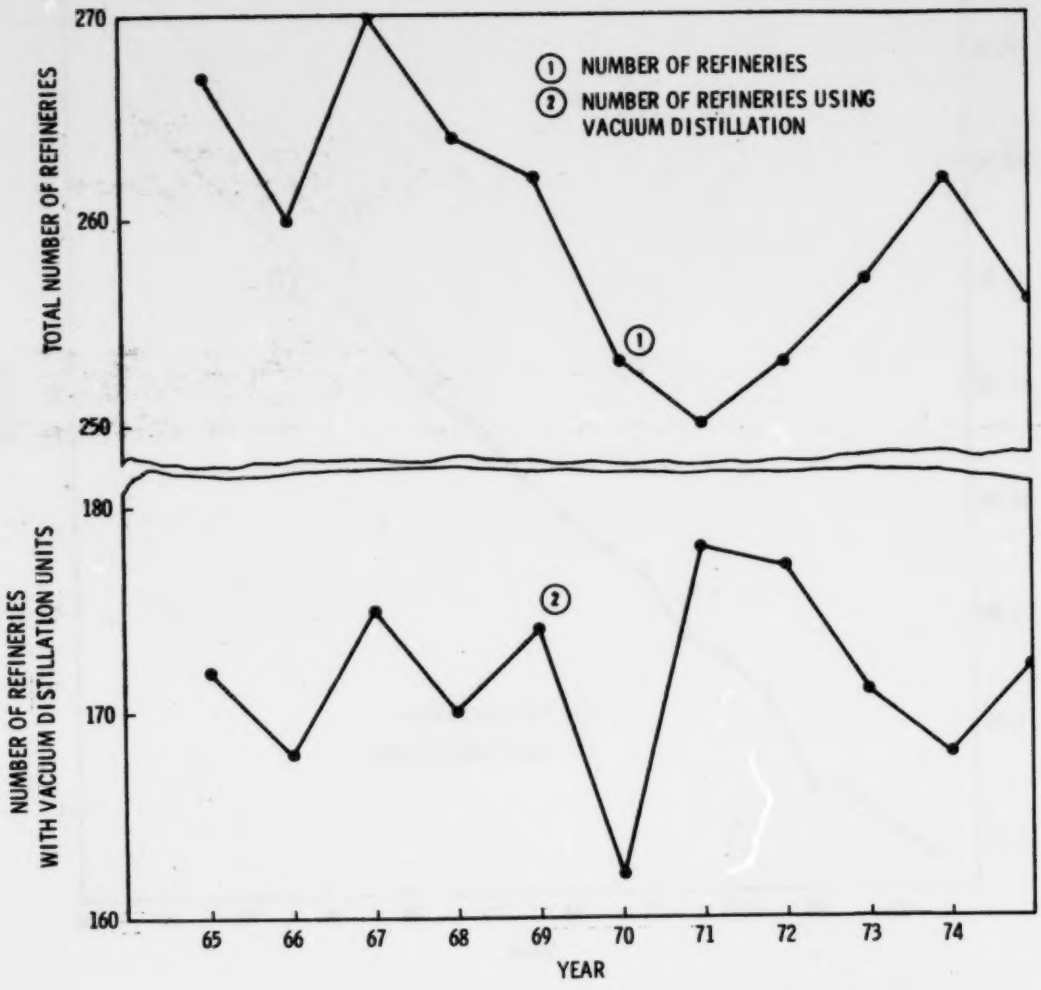

Figure 2. Total refineries and refineries with vacuum distillation units.

TABLE 3. NUMBER OF REFINERIES USING VACUUM DISTILLATION, 1965-1975[1-21]

Year	Number of refineries in operation	Number of refineries in operation that use vacuum distillation	Operating refineries[a] using vacuum distillation, %
1975	256	172	67.2
1974	262	168	64.1
1973	257	171	66.5
1972	253	177	70.0
1971	250	178	71.2
1970	253	162	64.0
1969	262	174	66.4
1968	264	170	64.4
1967	270	175	64.8
1966	260	168	64.6
1965	267	172	64.4

[a]Percent average of operating refineries using vacuum distillation was determined to be 66.0 ± 2.2%.

refineries using vacuum distillation, have remained fairly constant. By number, about 66% of refineries have used vacuum distillation.

Data from The Oil and Gas Journals's annual surveys[1-11] and Mineral Industry Surveys[12-21] were used to develop Table 4. The table lists yearly changes in vacuum distillation capacity due to plant modification or expansion, new capacity put on stream, and phaseout, and the number of plants involved in each case. The data developed for Table 4 were used to plot Figures 3 and 4. It should be noted that the major increases in vacuum distillation capacity are due to plant modifications. New plants represent only about 15% of the vacuum distillation capacity increases.

TABLE 4. REFINERY MODIFICATION, NEW PLANTS AND PHASEOUTS FOR VACUUM DISTILLATION UNITS[1-21]

Year	Increase in capacity due to expansion or modification		Increase in capacity due to new plants placed on stream		Decrease in capacity due to phaseout		Change in vacuum distillation capacity, m^3/s (b/sd)
	Capacity increase, m^3/s (b/sd)	Number of refineries	Capacity increase, m^3/s (b/sd)	Number of refineries	Capacity decrease, m^3/s (b/sd)	Number of refineries	
1975	0.293 (159,600)	12	0.0013 (750)	1	0.014 (7,800)	4	+0.280 (+152,550)
1974	0.374 (203,500)	23	0.001 (5,900)	1	0.023 (12,500)	4	+0.362 (+196,900)
1973	0.384 (208,700)	33	0.065 (35,500)	3	0.181 (98,400)	11	+0.268 (+145,800)
1972	0.381 (207,140)	22	0 (0)	0	0.171 (93,000)	10	+0.210 (+114,140)
1971	0.181 (98,550)	17	0.223 (121,500)	3	0.029 (15,900)	3	+0.375 (+204,150)
1970	0.673 (366,050)	27	0.188 (102,150)	4	0.040 (22;000)	4	+0.821 (+446,200)
1969	0.371 (201,800)	16	0 (0)	0	0.045 (24,600)	5	+0.326 (+177,200)
1968	0.130 (70,900)	19	0 (0)	0	0.102 (55,900)	3	+0.028 (+15,000)
1967	0.292 (158,700)	20	0.005 (3,000)	1	0.063 (34,275)	6	+0.234 (+127,425)
1966	0.258 (140,000)	15	0.064 (35,000)	1	0.163 (89,000)	8	+0.158 (+86,000)
1965	0.173 (94,500)	11	0 (0)	0	0.088 (48,050)	9	+0.085 (+46,450)
Average	0.286 (155,600 ± 33%)	18.1 ± 23%	0.044 (23,830 ± 107%)	1.1 ± 77%	0.081 (44,131 ± 48%)	5.5 ± 33%	+0.286 (+155,620 ± 48.3%)

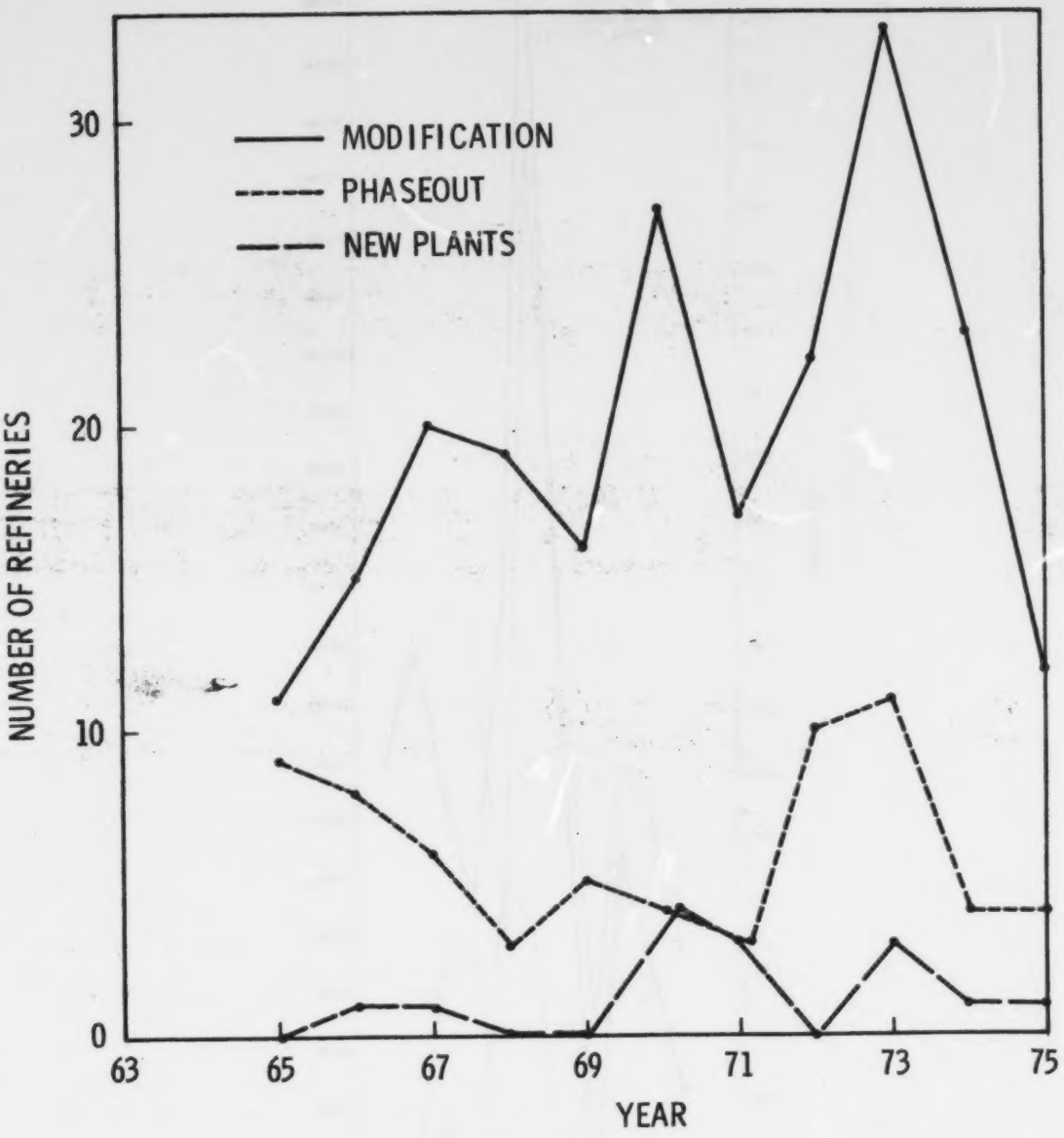

Figure 3. Change in the number of refineries with vacuum distillation due to plant modifications, new plants, and phaseouts.

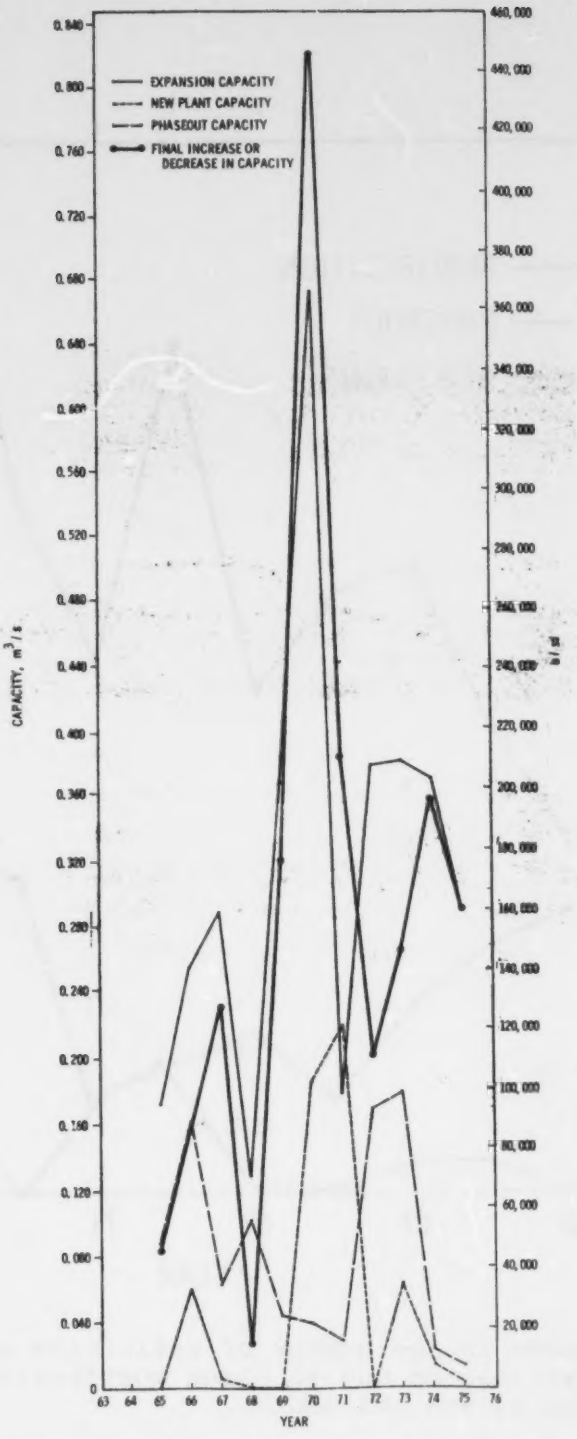

Figure 4. Change in vacuum distillation capacity due to plant modifications, new plants, and phaseouts.

SECTION IV

SOURCE DESCRIPTION AND TYPES OF EMISSIONS

A. PROCESS DESCRIPTION

1. Petroleum Refining Process

Crude oil, the charge stock for a refinery, is a mixture of many different hydrocarbons varying in chemical composition and physical properties. Physically, crude oil ranges from a thick, tar-like material to a light, colorless liquid.

The major constituents of crude oil are carbon and hydrogen, but impurities such as sulfur, sodium chloride, oxygen, nitrogen, and various metals (Fe, V, B, Mg, Si, Cu, Ni, Sr, Al, Ti, Ca, Mo, etc.)[22] are also present. Before the crude oil can be processed, some of the impurities, such as salts (chiefly sodium Chloride), are removed. Salts are separated out by washing the crude with water and breaking down the resulting emulsion, either chemically or electrically. Removal of the salt and other foreign material, referred to as "desalting," reduces both corrosion of equipment and plugging of heat exchangers.[22]

The desalted crude oil is separated by distillation into a narrow range of boiling products.[23] Distillation separates the crude oil into a number of predetermined fractions, depending on the desired feeds for processing in downstream units. Through cracking, reforming, treating, redistilling, air-blowing, and, if necessary, blending, the crude distillation products are then converted into finished products.[22] Figure 5 shows the unit operations involved in deriving the refinery products.

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[22]Laster, L. L. Atmospheric Emissions from the Petroleum Refining Industry. EPA-650/2-73-017 (PB 225 040/5), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, August 1973. 58 pp.

[23]Nack, N., K. Murthy, E. Stambaugh, H. Carlton, and G. R. Smithson, Jr. Development of an Approach to Identification of Emerging Technology and Demonstration Opportunities. EPA-650/2-74-048 (PB 233 646), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1974. 273 pp.

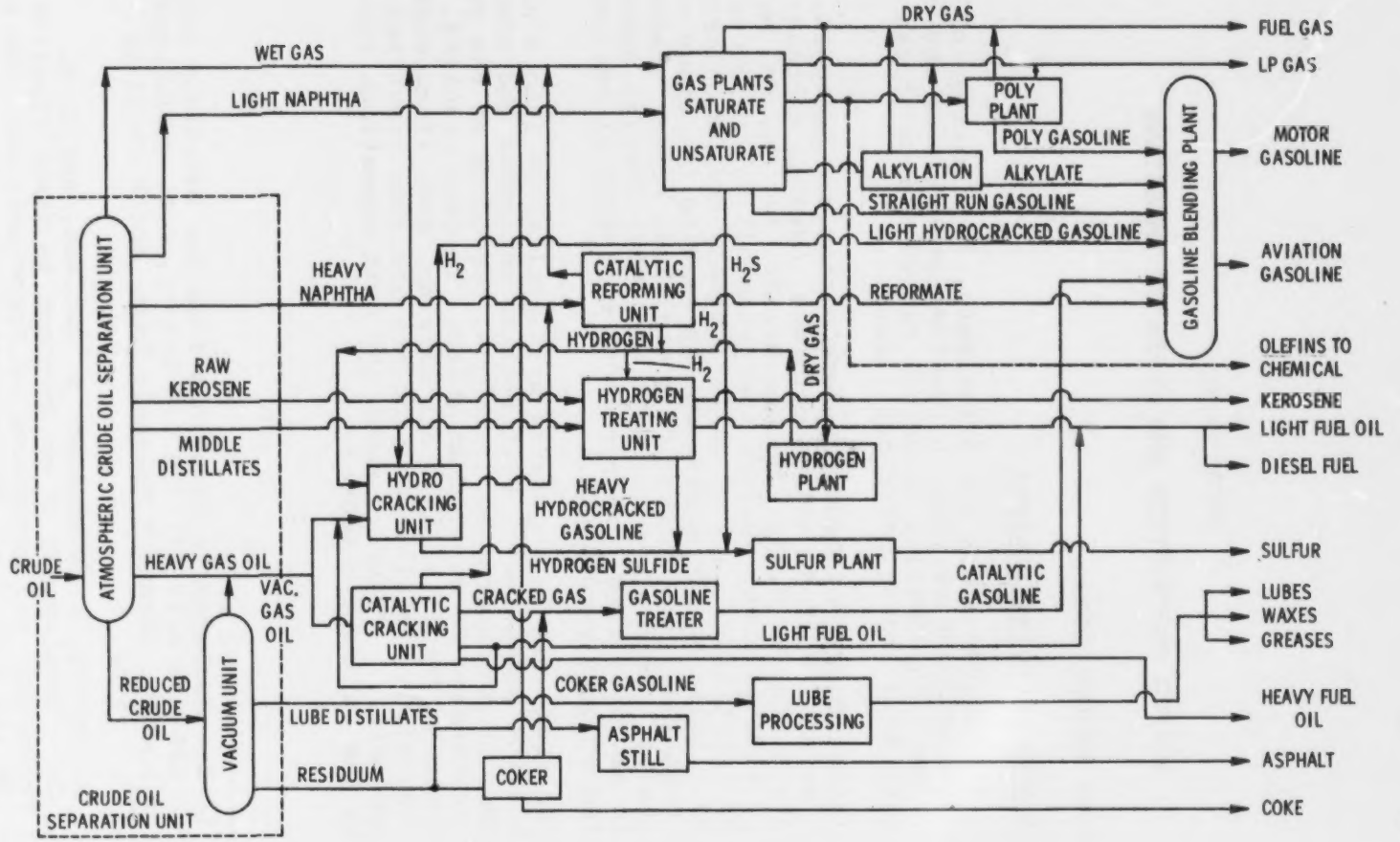

Figure 5. Block flow diagram of typical petroleum refining operations.[23]

Figure 6 shows a typical crude separation unit employing atmospheric and vacuum distillation. There are several possible equipment combinations to produce the required fractions from crude distillation. The combinations used at any particular refinery depend upon the type of crude being processed and upon the feedstocks required in further processing.[24]

In the crude oil atmospheric distillation unit, gasoline is the overhead product, and the intermediate products are naphtha, kerosene, light fuel oil, gas oil, and bottoms (or topped crude). In a very simple refinery, naphtha and lighter streams are obtained at the tower overhead, gas oil is obtained from a side stream, and topped crude is obtained from the still bottom. In a complex refinery, three to five side streams may be withdrawn.[23]

The gas products, including butane, propane, and methane, are used in refinery fuel gas systems, or they are sent to gas treating units. The overhead gasoline is condensed and then debutanized or depropanized to produce straight run gasoline.[24] The naphtha is blended into motor fuel or any of the several refinery products, or it is further processed to produce fractions to improve gasoline octane rating and/or reduce sulfur content. The kerosene may be chemically sweetened or hydrogen treated and sold. It also can be used in blending. The fuel oil may be sold as diesel fuel, or it may be hydrogen treated, hydrocracked, catalytically cracked, or blended. The gas oil may be sold as fuel oil, or it may be hydrogen treated, hydrocracked, catalytically cracked, or blended. The topped crude is usually fed to vacuum distillation although it may be also sold as heavier fuel oil, or it may be blended into fuels, hydrogen treated, or catalytically cracked.[23]

2. Vacuum Distillation Process

Vacuum distillation separates the residue from the atmospheric still into a heavy residual oil and one or more heavy gas oil streams.[23,24] Distillation carried out under vacuum allows the separation of these heavy distillates at reduced temperatures such that the oil does not thermally crack.[25] The atmospheric

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[24]The Cost of Clean Water. Vol. III, Industrial Waste Profile No. 5, Petroleum Refining. FWPCA Publication No. I.W.P.-5 (PB 218 222), U.S. Department of the Interior, Washington, D.C., November 1967. 197 pp.

[25]Benedict, Q. E. The Technique of Vacuum Still Operation. Petroleum Refiner, 31(1):103-106, 1952.

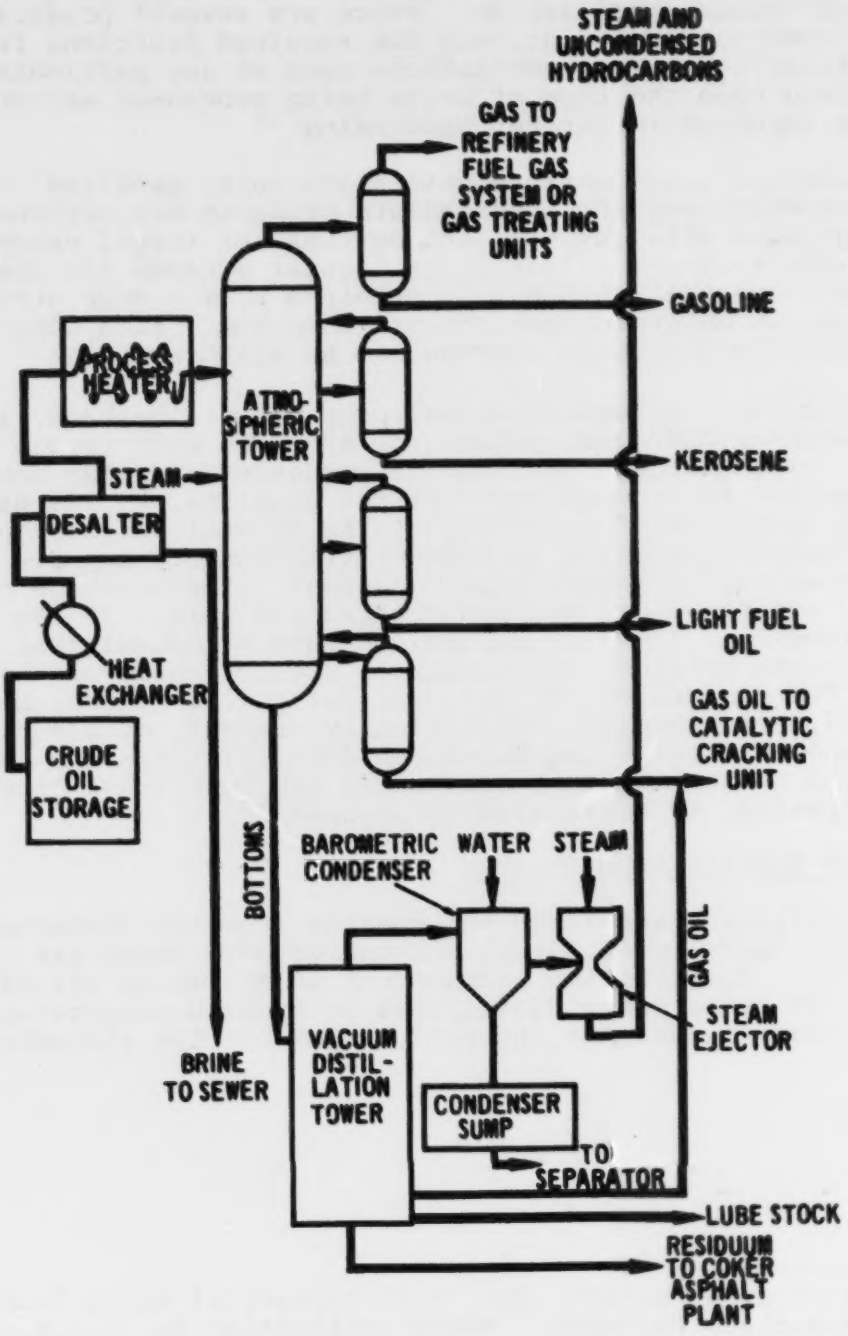

Figure 6. Typical crude oil separation unit employing atmospheric and vacuum distillation.[23]

residue is distilled at reduced pressures by using vacuum, steam, or a combination of the two.[26,27]

Depending mainly upon the crude feedstock and partially upon the individual refinery, the residual oil intermediate produce from the vacuum distillation unit may be sent to the asphalt plant, thermally cracked in a coker to make gasoline, cracked in a visbreaker to make distillate fuel oils, blended into a fuel oil, or hydrogen treated to remove sulfur and then blended into a fuel oil. With suitable feedstocks, the residual oil is sent to the lube oil process for manufacture into lubricating oil. The heavy distillate fraction from a paraffinic crude charge is sent to the lube oil plant either directly or through a hydrogen treating process. Other distillates are treated in the same way as the gas oil stream from the crude still, and may be catalytically hydrocracked, catalytically cracked, or used as fuel oil. The vacuum gas oil may be processed to remove sulfur by hydrogen treatment before catalytic cracking, or it may be used as a fuel oil.[23]

B. VACUUM DISTILLATION

Vacuum distillation is accomplished in one or two fractionation stages.[23,28-32] The major equipment items in a vacuum distillation unit are the preflash tower, the vacuum still, the steam strippers, and the vacuum producing system.[23-29]

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[26]Final Report - A Program to Investigate Various Factors in Refinery Siting, Revised Edition. Submitted to Council on Environmental Quality and Environmental Protection Agency by Radian Corporation (Radian Contract # 100-029), Austin, Texas, 24 July 1974. 620 pp.

[27]Petroleum Refinery Processes. In: Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Vol. 15. Interscience Publishers, New York, New York, 1968. pp. 1-76.

[28]Foster Wheeler Corporation. Crude Distillation, Two Stage Vacuum. Petroleum Refiner, 39(9):279, 1960.

[29]Dickerman, J. C., R. D. Raye, and J. D. Colley. The Petroleum Refining Industry. EPA Order No. 5-02-5609B, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 20 May 1975. 139 pp.

[30]Foster Wheeler Corporation. Crude Distillation, Three Stages. Hydrocarbon Processing, 45(9):271, 1966.

[31]Foster Wheeler Corporation. Crude Distillation. Hydrocarbon Processing, 53(9):106, 1974.

[32]Wharton, G. W., and E. P. Hardin. Three Stage Unit Improves Crude Split. Petroleum Refiner, 37(10):105-108, 1958.

1. Preflash Tower, Vacuum Still and Steam Strippers

Reduced crude from the atmospheric distillation unit is heated in a direct-fired furnace. In a two-stage vacuum unit, the heated crude is then charged to a preflash tower where a small quantity of distillate is produced as an overhead product. The bottom from the preflash tower in such a unit is charged to the vacuum fractioner for separation of additional distillate from the charge stock.[23,28,29] For a single-stage vacuum unit, the heated reduced crude from the atmospheric unit is charged directly to the vacuum fractionator. Vacuum residuum is recovered as the fractionation bottoms product. Steam stripping may or may not be used for separation of the distillate products.[26] The separation of well-fractionated distillate, such as lube oil stocks, utilizes steam stripping, whereas separation of heavy catalytic cracking feedstocks, such as vacuum gas oil, does not require steam stripping.[23] Figures 6 and 7 (pages 18 and 21) are flow diagrams of typical one- and two-stage vacuum units. When steam stripping is used, the steam mixes with the vaporized hydrocarbon fractions and is referred to as process steam.

Vaporization within the vacuum still is accomplished by reducing the partial pressure of the crude oil, primarily by the use of vacuum but also by the use of process steam. At a specific vacuum, the sum of the jet steam and process steam is a minimum.[33,34] Table 5 and Figure 8 illustrate how the total steam consumption varies with vacuum still temperature, condenser cooling water temperature, and pressure. They are based on the processing of 2.15×10^{-3} m^3/s (1,000 bd) of a conventional Midcontinent topped crude oil for the vaporization of material distilling up to about 510°C (950°F).[33,34]

2. Vacuum Producing Systems

Three types of vacuum producing systems may be used for refinery distillation:

- Steam ejectors with barometric condenser(s)
- Steam ejectors with surface condenser(s)
- Mechanical vacuum pumps[26]

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[33]Nelson, W. L. Petroleum Refinery Engineering, Fourth Edition. McGraw-Hill Book Company, New York, New York, 1958. pp. 252-261.

[34]Nelson, W. L. Questions on Technology: Noncondensable Gases Handled During Vacuum Distillation. The Oil and Gas Journal, 49:100, April 5, 1951.

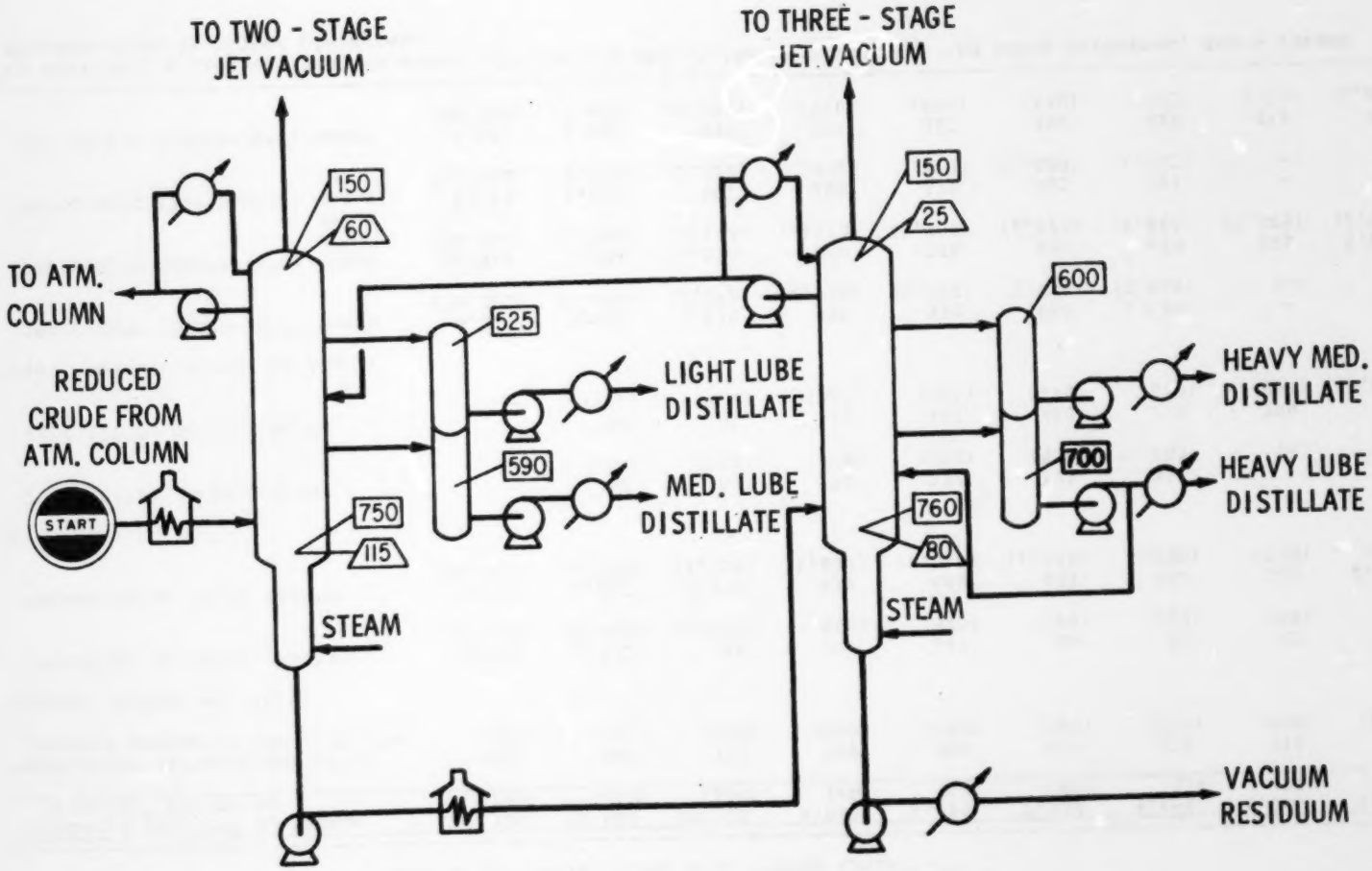

Figure 7. Crude distillation, two-stage vacuum.[28]

TABLE 5. TOTAL STEAM REQUIRED (APPROXIMATELY) IN VACUUM DISTILLATION FOR 2.15×10^{-3} m^3/s (1,000 b/d) TOPPED CRUDE[34,35]

Pressure produced by vacuum system,[a] Pa (mm Hg)	101,325 (760)	26,664 (200)	13,332 (100)	8,000 (60)	6,666 (50)	5,332 (40)	4,666 (35)	4,000 (30)	3,333 (25)
Temperature at vaporizer if no process stream is used, °C (°F)	510 (950)	443 (830)	415 (780)	399 (750)	390 (735)	385 (725)	379 (715)	375 (708)	371 (700)
Process stream, kg (lb)[a]									
Vaporizer at 382°C (720°F)	4,682 (10,300)	1,132 (2,490)	486 (1,070)	209 (460)	147 (325)	86 (190)	55 (122)	27 (54)	- (-)
Vaporizer at 360°C (680°F)	10,910 (24,000)	2,827 (6,220)	1,373 (3,020)	818 (1,800)	609 (1,340)	473 (1,040)	402 (885)	333 (733)	2,672 (580)
Jet steam, kg (lb)									
26°C (80°F) cooling water	- (-)	68 (150)	105 (232)	172 (378)	224 (492)	377 (830)	727 (1,600)		- (-)
21°C (70°F) cooling water	- (-)	66 (146)	101 (222)	142 (312)	167 (368)	218 (480)	273 (600)		914 (2,010)
Total steam required, kg (lb)									
360°C-26°C (680°F-80°F) water	10,910 (24,000)	2,895 (6,370)	1,478 (3,252)	990 (2,178)	833 (1,832)	850 (1,870)	1,129 (2,485)	- (-)	- (-)
360°C-21°C (680°F-70°F) water	10,910 (24,000)	2,894 (6,366)	1,519 (3,342)	960 (2,112)	776 (1,708)	691 (1,520)	675 (1,485)	685 (1,509)	1,177 (2,590)
382°C-26°C (720°F-80°F) water	4,682 (10,300)	1,200 (2,640)	591 (1,302)	381 (838)	371 (817)	463 (1,020)	783 (1,722)	- (-)	- (-)
382°C-21°C (720°F-70°F) water	4,682 (10,300)	1,198 (2,636)	587 (1,292)	351 (772)	315 (693)	304 (670)	328 (722)	414 (911)	914 (2,010)

[a] In addition, a pressure drop of about 1,333 Pa (10 mm) to the vaporizer for the lower pressures, and a larger pressure drop at higher pressures.

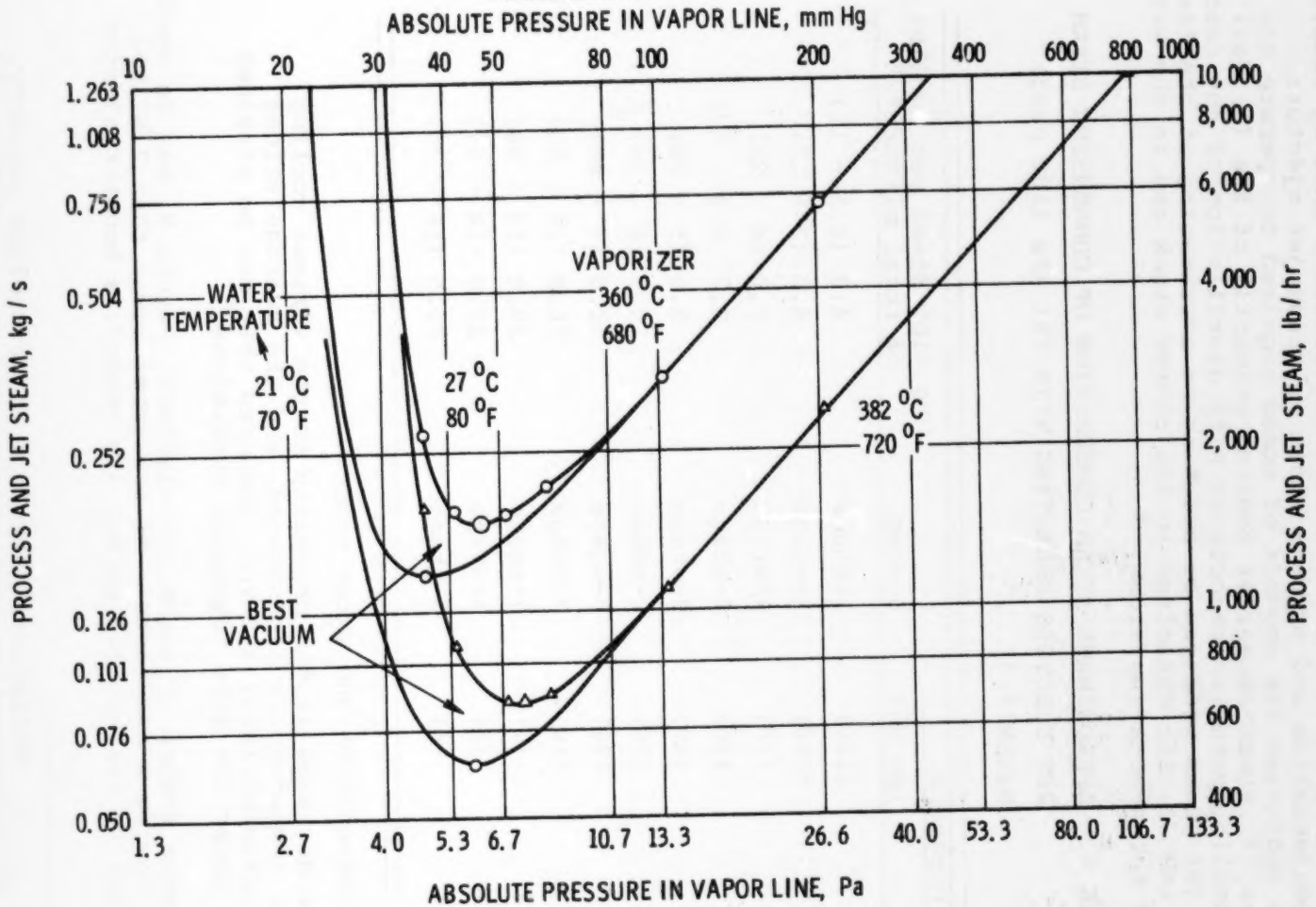

Figure 8. Examples of most economical pressure for vacuum tower operation, for 1.84 x 10^{-3} m^3/s (1,000 b/d) topped crude.[33,34]

a. Steam Ejectors with Barometric Condenser(s)--

Vacuum is created within the vacuum distillation unit by removal of noncondensables and process steam by steam jet ejectors. Table 6 indicates the amounts of steam required to operate the ejectors.[33] Noncondensables consist primarily of the (1) tail of lower boiling material associated with distillation of any feedstock, (2) gases produced by cracking or overheating of the feedstock, and (3) air dissolved in the charge stock and in the water used in the generating steam.[35]

TABLE 6. APPROXIMATE STEAM CONSUMPTION OF CONDENSING STEAM JET EJECTORS OPERATING WITH 791 kPa (100 psig) STEAM[33,34]

Pressure, kPa	Pressure, (mm Hg)	System	kg (lb) Steam per kg (lb) of total mixture[a,b]
26.7	(200)	2-stage	4.3 (2.5 - 11)
13.3	(100)	2-stage	6.0 (3 - 17)
9.33	(70)	2-stage	7.0 (4 - 23)
6.67	(50)	2-stage	8.2 (4.5 - 27)
5.33	(40)	2-stage	9.0 (5 - 30)
4.00	(30)	2-stage	10.2 (6 - 35)
2.67	(20)	3-stage	12.3 (7 - 40)
1.33	(10)	3-stage	16.8 (10 - 50)
0.933	(7)	3-stage	20.0 (12 - 58)
0.667	(5)	3-stage	23.0 (14 - 64)
0.533	(4)	3-stage	25.5 (16 - 70)

[a]Noncondensables and water vapor.

[b]The wide range is due primarily to the various cooling water temperatures encountered, and the average values (nonparenthesized) are very low ones that can be attained only under the most favorable conditions.

Two or more stages of steam jet ejectors, Figure 9, may be used, each following a condenser. If pressures lower than 2.67 kPa (20 mm Hg) to 3.2 kPa (24 mm Hg) are needed, a booster ejector

[35]Jones, H. R. Pollution Control in the Petroleum Industry. Noyes Data Corporation, Park Ridge, New Jersey, 1973. 322 pp.

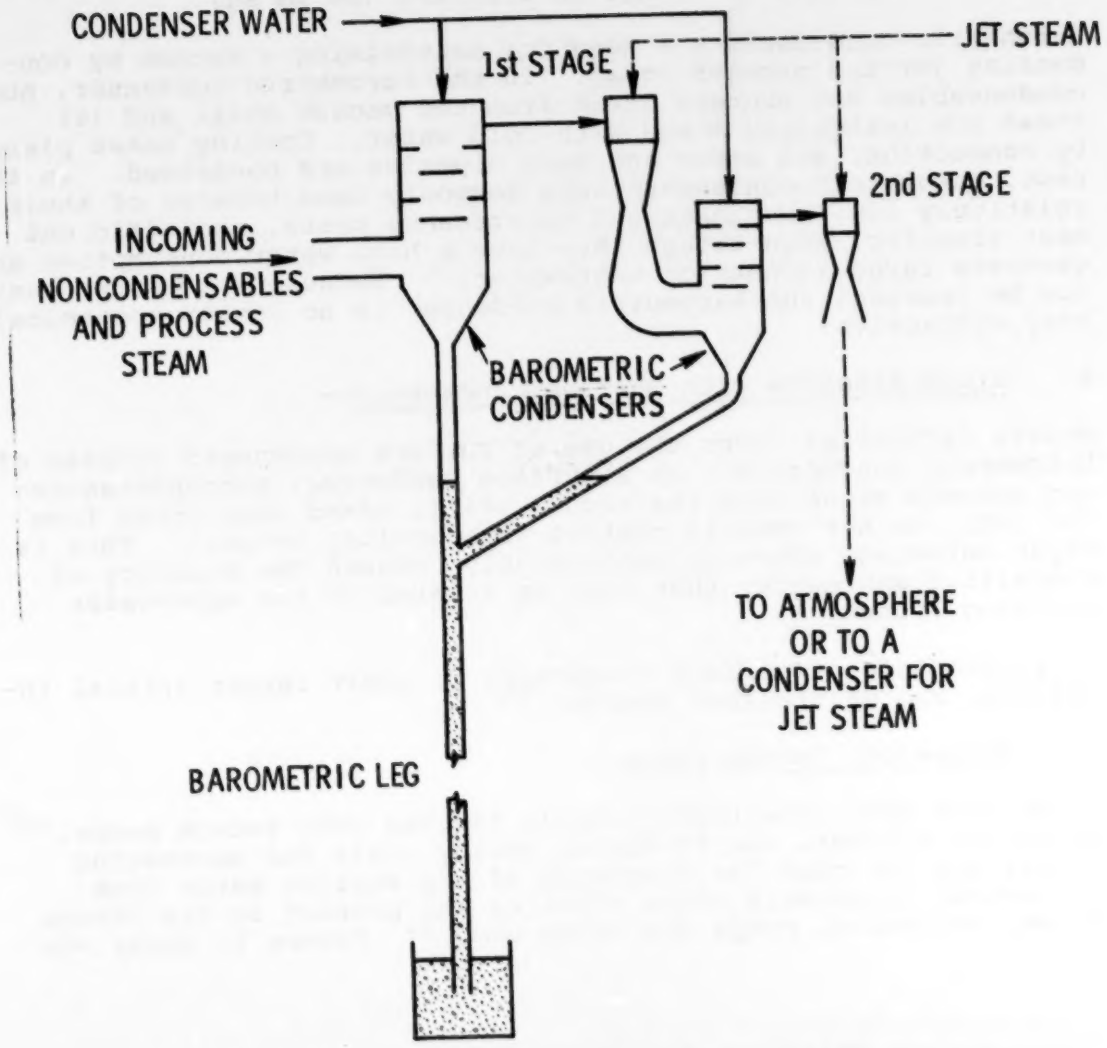

Figure 9. Two stages of steam jet ejectors with a barometric condenser.[33,34]

and two or three stages of steam jet ejectors are usually required, Figure 10. The booster ejector is simply a large steam ejector that is installed between the vacuum still and the first condenser. A booster ejector enormously increases the amount of jet steam required because it must handle all the process steam as well as noncondensables.[33] The steam requred to operate the booster ejector is included in the values shown in Table 6 in the pressure range of 0.533 kPa (4 mm Hg) to 2.67 kPa (20 mm Hg).

Barometric condensers are used for maintaining a vacuum by condensing jet and process steam. In the barometric condenser, noncondensables and process steam from the vacuum still and jet steam are intimately mixed with cold water. Cooling takes place by conduction, and steam and some organics are condensed. In the past, barometric condensers were commonly used because of their relatively low investment and maintenance costs, and efficient heat transfer, even though they have a high water consumption and generate large amounts of wastewater.[36] Because wastewater must now be treated, the barometric condenser is no longer economically very attractive.

b. Steam Ejectors with Surface Condensers--

Modern refineries favor the use of surface condensers instead of barometric condensers. In a surface condenser, noncondensables and process steam from the vacuum still, mixed with steam from the jets, do not come in contact with cooling water.[24] This is a major advantage since it considerably reduces the quantity of emulsified wastewater that must be treated in the wastewater treating system.[36]

A disadvantage of surface condensers is their larger initial investment and maintenance expense.[37]

c. Mechanical Vacuum Pumps--

Steam jets have been traditionally favored over vacuum pumps.[38] Recently, however, due to higher energy costs for generating steam, and the cost for disposing of the cooling water from barometric condensers where organics are present in the vacuum steam, mechanical pumps are being used.[38] Figure 11 shows the

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[36]Hydrocarbon Emissions from Refineries. Publication No. 928. American Petroluem Institute, Committee on Refinery Environmental Control, Washington, D.C., July 1973. 63 pp.

[37]Thomson, S. J. Techniques for reducing refinery wastewater. The Oil and Gas Journal, 68(40):93-98, 1970.

[38]Monroe, E. S. Vacuum pumps can conserve energy. The Oil and Gas Journal, 73(5):126-128, 1975.

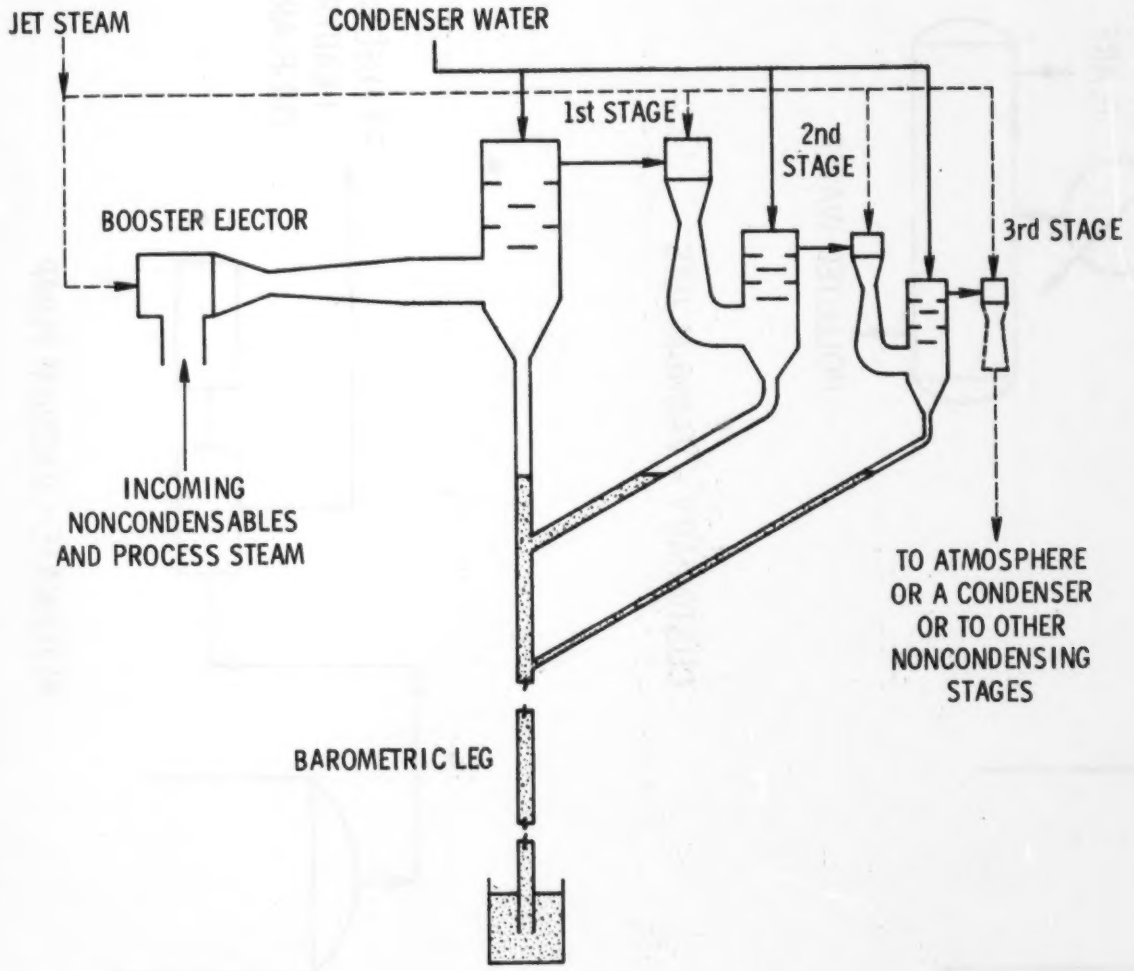
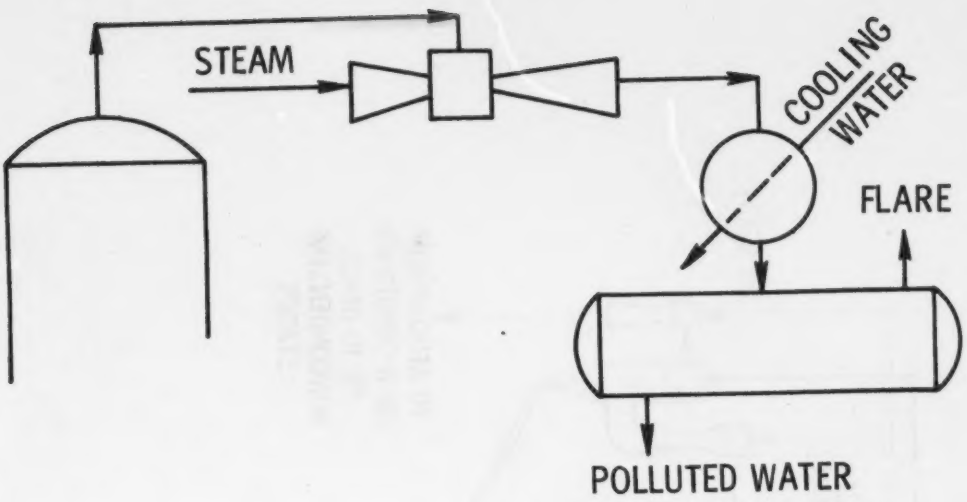
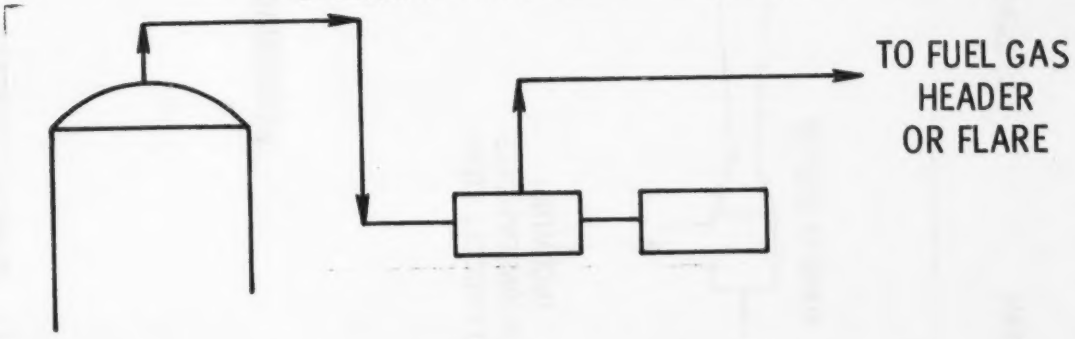


Figure 10. Booster ejector, barometric condenser and two or more steam jet ejector stages for low-vacuum systems.[33,34]



CUSTOMARY - VACUUM JETS



ALTERNATE - VACUUM PUMP

Figure 11. Noncondensable removal - vacuum pump and steam jet ejector.[37]

general arrangement for the use of vacuum pumps and steam jet ejectors for removal of noncondensables.

Frictional, electrical, auxiliary cooling, and pumping losses, vaporization of sealing liquids, and internal leakage prevent vacuum pumps from approaching their theoretical energy requirements.

Actual data were collected for a number of commercial applications (Table 7), and they were evaluated for purchased energy input at the plant boundary line (Table 8). Overall thermal efficiency was then plotted (Figure 12). Results clearly show that steam jets are inefficient users of energy.[38]

C. EMISSIONS

1. Locations and Descriptions

Vacuum distillation units used in the petroleum refinery industry are closed systems under vacuum. Although the only source of hydrocarbon emission to the atmosphere is the fractionator's vacuum system,[39] vacuum distillation operations can cause both atmospheric and wastewater pollution.[29]

a. Sources of Atmospheric Pollution--

The only source of atmospheric emissions from vacuum distillation operations is the fractionator's vacuum system.[23,26,29-33,39-46] In the vacuum distillation column, gases arise mainly from mild thermal cracking of crude, dissolved air or gas within the crude, and light ends present in the crude.[34] These gases are removed from the vacuum still by the vacuum system. Gases from the tower are passed through a barometric or surface condenser, where steam and some of the vapors are condensed.[47] Hydrocarbons which do not condense within such a condenser are called noncondensables. The quantity of noncondensables is related to the final water temperature obtained in the condenser; the lower the temperature within

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[39] Burklin, C. E., E. C. Cavanaugh, J. C. Dickerman, S. R. Fernandes, and G. C. Wilkins. Control of Hydrocarbon Emissions from Petroleum Liquids. EPA-600/2-75-042 (PB 246 650), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1975. 245 pp.

[40] Atmospheric Emissions from Petroleum Refineries. A Guide for Measurement and Control. Public Health Service Publication No. 763 (PB 198 096), U.S. Department of Health, Education, and Welfare, Washington, D.C., 1960. 56 pp.

[41] Compilation of Air Pollutant Emission Factors. Publication No. AP-42, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1975. pp. 9.1-1 to 9.1-8.

TABLE 7. VACUUM PUMP ENERGY REQUIREMENTS[a,38]

Vacuum system	Initial absolute pressure, kPa (mm Hg)				
	66.7 (500)	33.3 (250)	16.7 (125)	8.3 (62.5)	1.3 (10)
Steam jet	7.9×10^5 (750)	3.2×10^6 (3,013)	8.0×10^6 (7,534)	6.9×10^6 (6,511)	2.2×10^7 (20,508)
Liquid ring	7.2×10^4 (68)	1.6×10^5 (149)	3.2×10^5 (307)	6.1×10^5 (573)	5.1×10^6 (4,835)
Blower	3.1×10^4 (24)	1.3×10^5 (118)	1.9×10^5 (181)	3.9×10^5 (373)	- -
Mechanical pump	4.8×10^4 (45)	1.0×10^5 (98)	1.9×10^5 (181)	2.9×10^5 (273)	1.3×10^6 (1,195)

[a]Joules (BTU) required to pump 454 g (1 lb) of air to atmospheric pressure.

TABLE 8. COMPARATIVE COSTS[a,38]
(cents)

Vacuum system	Initial absolute pressure, kPa (mm Hg)				
	66.7 (500)	33.3 (250)	16.7 (125)	8.3 (62.5)	1.3 (10)
Steam jet	0.12	0.49	1.24	1.07	3.36
Liquid ring	0.04	0.09	0.18	0.34	2.83
Blower	0.02	0.07	0.11	0.22	-
Mechanical pump	0.03	0.06	0.11	0.16	0.70

[a]Cost to pump 454 g (1 lb) of air to atmospheric pressure.

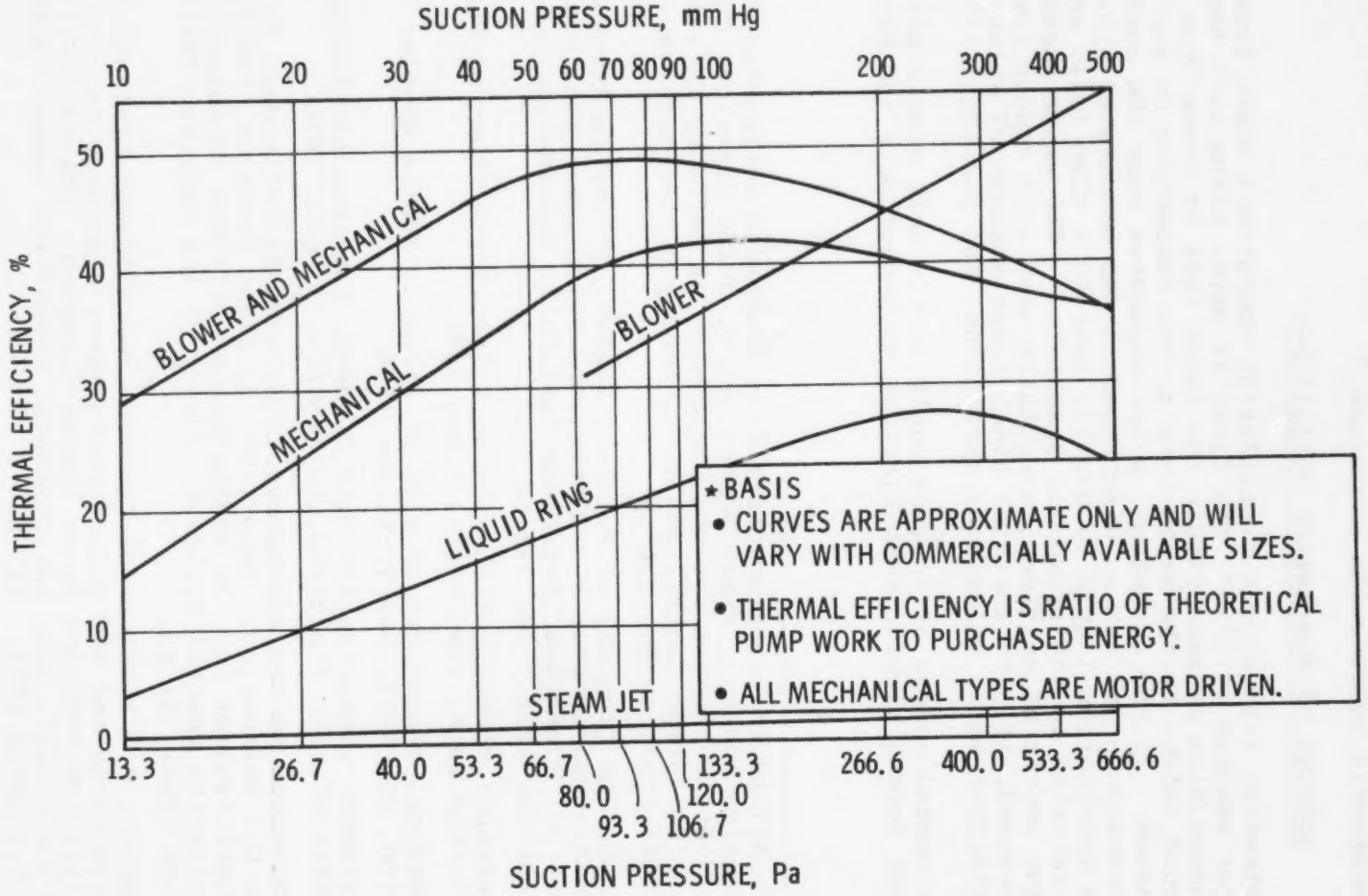
SUCTION PRESSURE, mm Hg
10 20 30 40 50 60 70 80 90 100 200 300 400 500
THERMAL EFFICIENCY, %
50
40
30
20
10
0
BLOWER AND MECHANICAL
MECHANICAL
BLOWER
LIQUID RING
STEAM JET
★BASIS
• CURVES ARE APPROXIMATE ONLY AND WILL VARY WITH COMMERCIALLY AVAILABLE SIZES.
• THERMAL EFFICIENCY IS RATIO OF THEORETICAL PUMP WORK TO PURCHASED ENERGY.
• ALL MECHANICAL TYPES ARE MOTOR DRIVEN.
13.3 26.7 40.0 53.3 66.7 80.0 93.3 106.7 133.3 120.0 266.6 400.0 533.3 666.6
SUCTION PRESSURE, Pa

Figure 12. Vacuum pump efficiency.[38]

the condenser, the lower the volume of noncondensables. If emitted to the atmosphere, these noncondensables are a source of atmospheric hydrocarbon emossions.[36]

b. Sources of Wastewater Pollution--

Wastewater from vacuum distillation operations comes from three major sources.[24,35,48] The first is water along with the noncondensables present within the crude that is drawn from the vacuum column by the steam jets to the barometric or surface condensers. In the condenser, water separates from the condensed hydrocarbons and can be discharged to the wastewater system.[24,35] The hydrocarbon liquid is usually sent to a slop (oily water) tank or recycled to the crude oil desalter.[31] The water phase is a major source of sulfides, especially when sour crudes are being processed; it also contains significant amounts of soluble and emulsified oils, chlorides, mercaptans, and phenols.[24,26,29,35]

The second source of aqueous waste is the very stable oil emulsions formed within steam ejectors or vacuum jets and barometric

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[42]Emissions to the Atmosphere from Petroleum Refineries in Los Angeles County. Final Report No. 9, Joint District, Federal and State Project for the Evaluation of Refinery Emissions. Air Pollution Control District, County of Los Angeles, California, 1958. 136 pp.

[43]Manual on Disposal of Refinery Wastes, Volume on Atmospheric Emissions, Chapter 7 - Hydrocarbon Emissions. Publication No. 931. American Petroleum Institute, Washington, D.C., February 1976. pp. 7-1 to 7-17.

[44]Personal communication with R. Fritz, Exxon Chemical Company, Florham Park, New Jersey, 3 May 1976.

[45]Personal communication with A. Stesani, Foster Wheeler Corporation, New York, New York, May 1976.

[46]Personal communication with P. Hess, Bay Area Air Pollution District, San Francisco, California, 1 April 1976.

[47]Emissions to the Atmosphere from Eight Miscellaneous Sources in Oil Refineries. Report No. 8, Joint District, Federal and State Project for the Evaluation of Refinery Emissions. Air Pollution Control District, County of Los Angeles, California, June 1958. 51 pp.

[48]Halper, M. Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Petroleum Refining Point Source Category. EPA-440/1-74-014-a (PB 238 612), U.S. Environmental Protection Agency, Washington, D.C., April 1974. 207 pp.

condensers used to create the reduced pressure in vacuum distillation units.[24,35] This problem is eliminated when barometric condensers are replaced with surface condensers.[24,35]

Steam stripping to separate the distillation products[37] is the third source of wastewater.

Most of the oil entering the wastewater treatment facility may be removed using API separators, but some residual hydrocarbon remain dissolved in the wastewater. Due to the high air-water contact occuring in waste treatment processes, these dissolved hydrocarbons may be evaporated and emitted to the atmosphere.[39]

2. Emission Factors

The normal concentration of the noncondensable vapors is in the range of 43 to 368.5 g/m^3 (15 to 130 $lb/10^3b$) of charge to the vacuum furnace.[22,26,33,34,36,39,41,43,49-51] The typical compositions of noncondensable vapors are given in Table 9.

The quantity and composition of noncondensable vapors is dependent on many factors, including composition of charge to the vacuum tower, operating conditions within the tower, products desired, and types of condensers used.[36]

The refining industry has been increasingly dependent on imported crude oil, which generally contains a higher percentage of sulfur than domestic crude oils. These sulfur-bearing crudes generate a higher concentration of hydrogen sulfide in the noncondensable vapor. Refinery products vary with location, climate, and season. In the operation of a vacuum distillation unit, there is usually one product which has a higher value than the other products. Operating variables are therefore adjusted to maximize the yield of this product at the expense of less valuable products.[25] All these factors will have some influence on the amount and composition of the noncondensables.

Lowering cooling water temperatures within the barometric condenser can reduce the amount of noncondensables emitted. However, this would result in an increase in wastewater problems.[36]

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[49]Nelson, W. L. Questions on Technonogy: What is an Economical Vacuum to Use. The Oil and Gas Journal, 54:171-172, May 14, 1956.

[50]Chave, C. T. Vacuum Equipment in the Oil Refinery. Refiner and Natural Gasoline Manufactorer, 15(2):45-50, 1936.

[51]Air Pollution Engineering Manual, Second Edition, J. A. Danielson, ed. Publication No. AP-40, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1973. 987 pp.

TABLE 9. TYPICAL NONCONDENSABLE VAPOR COMPOSITION[44]

Component, mole %	Dry gas
Hydrogen	2.9
Methane	17.3
Ethane	7.9
Ethylene	0.6
Propane	9.4
Propylene	0.0
n-Butane	14.6
Isobutane	5.0
Butenes	2.4
n-Pentane	5.3
Isopentane	7.1
Pentenes	3.3
Hexanes	1.4
Hexenes	0.6
Benzene	0.1
Toluene	Trace
Heptenes	<0.1
Heptanes	Trace
Octenes	0.0
Octanes	0.0
Nitrogen	6.0
CO_2	1.3
Air	0.9
H_2S	8.7
CH_3SH	<0.1
CO	4.8
	100

Table 10 gives the current emission rate from a typical refinery operating a vacuum distillation unit that is not using any hydrocarbon emission reduction system.

TABLE 10. CURRENT EMISSION RATE FROM A TYPICAL UNCONTROLLED REFINERY VACUUM DISTILLATION UNIT

Emission source	Gas volume, m^3/s (scfm)	Gas composition, ppm					Emission rate, g/m^3 (lb/1,000 b)
		HC	H_2S	CO	H_2	Air	
Vacuum system	0.06 (130)	750,000	90,000	50,000	30,000	80,000	370 (130)

SECTION V

BEST APPLICABLE SYSTEMS OF EMISSION REDUCTION

Available technology used in petroleum refineries for controlling hydrocarbon emissions from vacuum distillation units has been extremely effective.[42,47] The petroleum industry has controlled such hydrocarbon emissions primarily for safety and economic reasons. The technology discussed earlier which would assure minimum (zero) emission rates from vacuum distillation units has been demonstrated by the refineries. It is estimated that 83.3% (by number) of the refineries processing 91.7% of the crude have achieved ≈100% emission control from vacuum distillation operations. Regulations emphasizing the requirement to use available control systems can accomplish complete control.

There are currently two methods available by which noncondensables may be effectively eliminated: vapor recovery or disposal, and adsorption.[29,36,39,52]

A. VAPOR RECOVERY OR DISPOSAL

In the petroleum refining industry, vapor recovery is the most commonly used method for controlling hydrocarbon emissions from vacuum distillation units.[36,52] Noncondensable vapor from the vacuum still, mixed with steam from the steam jets, is condensed in a barometric or surface condenser when its temperature is lowered with cooling water.[33,36,42,47,49] The portion of noncondensable vapor that does not condense in the condenser is vented to the nearest available firebox of a boiler or heater and burned to provide useful heat.[1,26,29,36,39,40,42,43,47,52]

In the vapor disposal system, the noncondensables not condensed in barometric or surface condensers are vented to an afterburner to be flared.[1,29,36,39,40,42,43,47]

B. VAPOR ABSORPTION

Hydrocarbon emissions from vacuum distillation stills can be controlled by installation of an absorption system between the vacuum

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[52]Sims, A. V. Field Surveillance and Enforcement Guide for Petroleum REfineries. EPA-450/3-74-042 (PB 236 669), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974. 369 pp.

still and the first stage vacuum jet.[36,39] The absorption system passes noncondensables from the vacuum still through a packed absorber column where they are absorbed by cascading lean oil.[39] Stripped air is vented from the top of the absorber column to the first stage vacuum jet. The lean oil for the absorber is generated by evaporating off all the light ends from heating oil.[39]

An absorption system can only be used where the quantity of noncondensables makes the cost of the installation economically justifiable.[27,39]

Table 11 summarizes the hydrocarbon emission level that is achievable with the best applicable emission reduction systems.

TABLE 11. ACHIEVABLE HYDROCARBON EMISSION LEVELS WITH BEST CONTROL TECHNIQUES

Emission point	Control technique	Achievable hydrocarbon emission level	
		ppm	lb/hr
Vacuum system	Vapor recovery or disposal	≈0	≈0

SECTION VI

STATE AND LOCAL AIR POLLUTION REGULATIONS

State regulations pertaining to air pollution were obtained and reviewed, and those applicable to this task were extracted and summarized.[a] State regulations are frequently changed and/or updated. The regulations reviewed for this task had been updated to April 1976.

Regulations vary from state to state, but in most cases they were found to be vague on emissions from specific refinery operations. An attempt has been made to summarize the present status of the state and local air pollution regulations applicable to petroleum refineries.

In the state regulations, hydrocarbon emissions may be referred to as hydrocarbon, volatile organic, organic material, organic, and/or oxidant emissions.

Some states have general hydrocarbon emission regulations applicable to the petroleum refining industry. Other states use ambient air quality standards. Finally, some states have no regulations that could be applied to hydrocarbon emissions from the petroleum industry. Defining the extent to which the states do or do not enforce any of these regulations for cases of petroleum refining was not attempted. States with similar regulations were grouped into the following three categories:

I. States with hydrocarbon emission regulations specific to refineries and/or those that can be extended and applied to refineries.

II. States primarily utilizing air quality standards.

III. States with no applicable hydrocarbon emission standards.

Table 12 lists each state and indicates its regulation category. The full text of regulations considered under this task is not

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[a]All state and local regulations have been submitted separately.

TABLE 12. STATE HYDROCARBON REGULATIONS

State	Category I	Category II	Category III	State	Category I	Category II	Category III
Alabama	✓			Missouri			✓
Alaska			✓	Montana			✓[b]
Arizona	✓			Nebraska			✓
Arkansas	✓			Nevada[a,c]		✓[b]	
California			✓[b]	New Hampshire[a,c]		✓	
Los Angeles			✓[b]	New Jersey	✓		
Colorado	✓			New Mexico	✓[d]		
Connecticut[a,c]	✓			New York	✓		
Delaware			✓	New York City	✓		
Florida			✓[b]	North Carolina[a,c]	✓		
Georgia			✓	North Dakota[a]	✓		
Hawaii	✓			Ohio	✓		
Idaho[a,c]	✓			Oklahoma	✓		
Illinois	✓			Oregon		✓	
Chicago	✓			Pennsylvania	✓		
Indiana	✓[d]			Rhode Island[a,c]	✓		
Iowa[a,c]		✓		South Carolina[a,c]		✓	
Kansas	✓			South Dakota[a,c]	✓		
Kentucky			✓[b]	Tennessee			✓
Louisiana	✓[d]			Texas	✓		
Maine[a,c]			✓	Utah		✓	
Maryland	✓			Vermont[a,c]			✓
Baltimore	✓			Virginia	✓		
Massachusetts[a,c]	✓			Washington	✓		
Michigan			✓	West Virginia			✓
Minnesota		✓		Wisconsin	✓		
Mississippi			✓	Wyoming		✓	
				District of Columbia[a,c]	✓		

[a] States where no vacuum distillation operations exist.

[b] States with some regulations for hydrocarbon emissions, but primarily in the area of storage of organic material.

[c] States where no refineries exist.

[d] States with some hydrocarbon emission regulations specifically spelled out for petroleum refineries.

presented in this report. The texts of all pertinent hydrocarbon regulations for each state were extracted and furnished to the EPA under separate cover.

A review of the state hydrocarbon emissions regulations indicates that even the best regulations (Category I) are not comprehensive enough to assure the reduction in refinery hydrocarbon emissions from vacuum distillation operations that would be possible by the use of available control technology.

A. CATEGORY I

This category covers those states with regulations for hydrocarbon or organic emissions that can be extended to apply to refineries, as well as those with regulations specific to refining operations. Examples of regulations in this category follow.

1. Volatile Organic Compound Water Separation

Compartments that receive water containing volatile organic compounds from processing, refining, treating, storing, or handling these compounds must be equipped with one of the following:

- Sealed openings and gas-tight gauging and sampling devices
- Floating roof
- Vapor recovery system
- Other system of equal efficiency

2. Waste Gas Disposal

Gas stream must be properly burned in a direct-flame afterburner with an indicating pyrometer or its equal.

B. CATEGORY II

This category includes those states that use primarily hydrocarbon ambient air standards often supplemented with the Federal Ambient Air Standards. An example of these kinds of regulations for hydrocarbons is:

> Three-hour average (6 a.m. to 9 a.m.) - hydrocarbon concentration limit of 160 micrograms per cubic meter

C. CATEGORY III

The states in this category have no regulations applicable to hydrocarbon emissions.

SECTION VII

ESTIMATED EMISSION REDUCTION

Model IV was developed by the EPA for use by the Emission Standards and Engineering Division. It is used to assess numerous industries for the purpose of establishing priorities for setting standards. The model mathematically expresses the differential in atmospheric emissions that can be expected with and without NSPS.[53]

The model by which emission differential was calculated uses 1975 capacity as the baseline to which estimated growth and obsolescence rates over the next 10 years are applied. This gives the new and modified capacity that can be regulated by NSPS in the period 1975 to 1985. The best available level of control is then applied to this capacity to determine the level of emissions that may be achieved under controls required by NSPS in 1985. Similarly, another set of emission levels is determined for 1985 by applying to the current, new, and modified capacity the current levels of emissions. Both sets of emission levels represent maximum values based on capacity. The capacity utilization factor is used to convert emission levels from operation at capacity to operation at production rates anticipated in 1985. The difference between the two values of emission levels represents the control effectiveness of NSPS.

Certain variables needed to develop the relationship between projected emissions under baseline year levels of control and controls required under NSPS for petroleum refinery vacuum distillation operations will be defined in three groups: industrial prime variables, emission factors, and intermediate variables.

A. INDUSTRIAL PRIME VARIABLES

1. Normal Fractional Utilization, "K"

The variable "K" represents that fraction of total existing capacity which is brought into service to produce a given output.

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[53] Hopper, T. G., and W. A. Marrone. Impact of New Source Performance Standards on 1985 National Emissions from Stationary Sources, Volume I. EPA Contract 68-02-1382, Task 3, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 24, 1975. 178 pp.

By applying this factor to the capacity-based values of A, B, and C, actual production output can be determined.[53]

The purpose of "K" is to convert design capacity to production capacity. Production figures are then applied to emission factors to calculate actual emissions. Petroleum refineries report production figures either in barrels per calendar day or barrels per stream day.[1-11]

Production figures used in this report were obtained from The Oil and Gas Journal. The production figures for vacuum distillation are reported in barrels per stream day, having used a conversion factor of 0.95 to convert calendar day figures to stream day figures. The factor 0.95 is not a ratio of production capacity to design capacity and does not satisfy the above definition of "K." But for this report production data reported in barrels per stream day were used, and "K" was therefore given the value of 0.95.

2. Production Capacity, "A"

The variable "A" is defined as the industrial production capacity in the baseline year.[53] For 1975, the vacuum distillation capacity has been reported in the literature to be 10.44 m^3/s (5,762,745 barrels per stream day).[1] Therefore, "A" was given the value 10.44 m^3/s (5,672,893 b/sd).

3. Increase in Industrial Capacity Over Baseline Year Capacity, "P_c"

The variable "P_c" is defined as the average anticipated growth rate in industrial capacity during the period between the baseline year and 1985.[53]

The production capacity data for vacuum distillation from 1965 through 1975 shown in Table 2 were plotted, Figure 13.[1 11] Increase in capacity over 10 years was 5.1% a year based on 1965 production. Assuming that the increase in capacity would remain constant through 1985, P_c was calculated using simple and compound growth.[53]

a. Using Simple Growth (P_{ca})--

$$P_{ca} = \frac{\text{Capacity in year "x" - capacity in year "y"}}{(x - y)\ \text{Capacity in 1975}}$$

where $x > y$

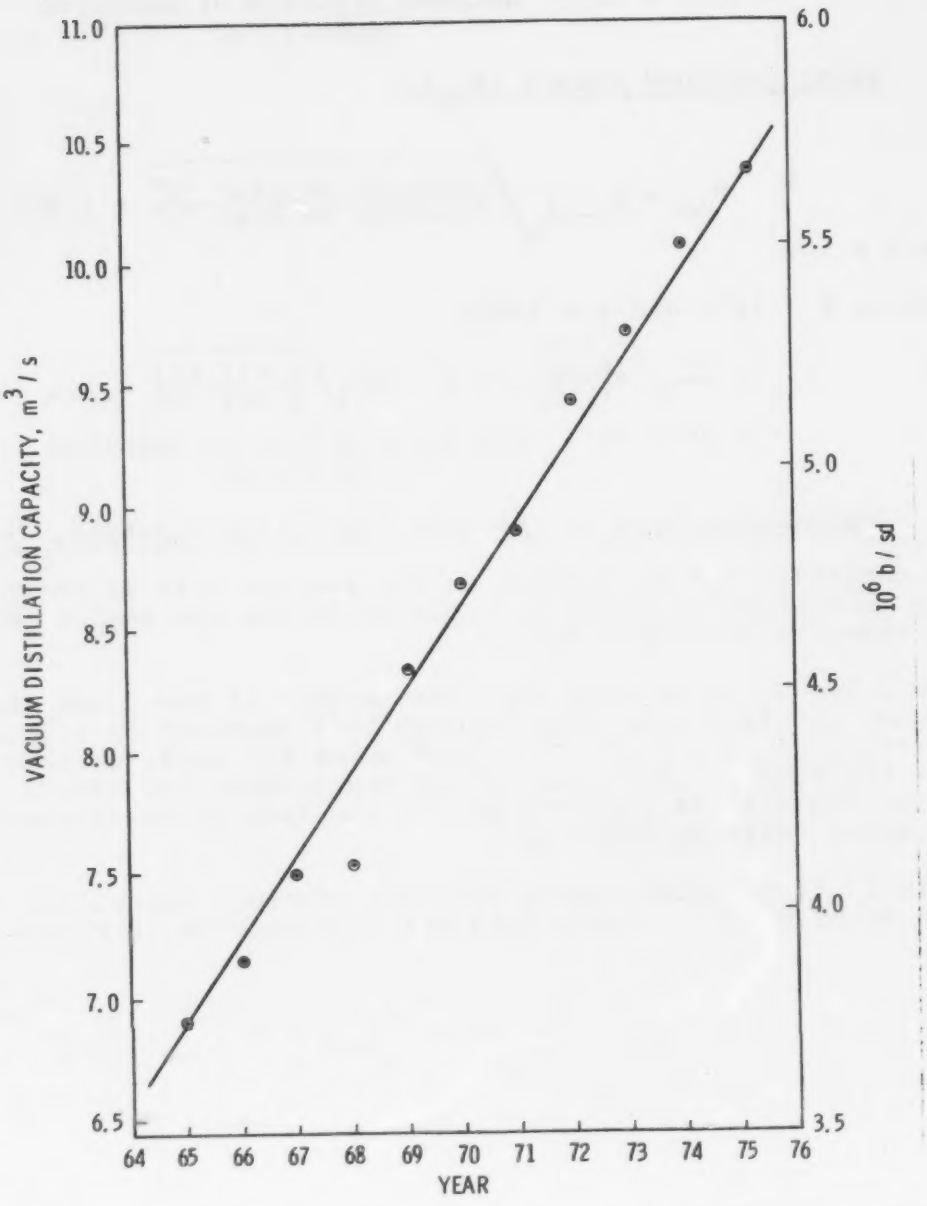

Figure 13. Vacuum distillation capacity, 1965-1975.

Letting x = 1975 and y = 1965:

$$P_{ca} = \frac{10.44 - 6.92}{10 \times 10.44} \left(\frac{5,672,893 - 3,762,745}{10 \times 5,762,745} \right)$$

$$= 3.37 \times 10^{-2} \text{ decimal fraction of baseline capacity/yr}$$

b. Using Compound Growth (P_{cb})--

$$P_{cb} = \sqrt[x-y]{\frac{\text{Capacity in year "x"}}{\text{Capacity in year "y"}}} - 1.0$$

where x > y

Letting x = 1975 and y = 1965:

$$P_{cb} = \sqrt[10]{\frac{10.44}{6.92}} - 1.0 \quad \sqrt[10]{\frac{5,672,893}{3,762,745}} - 1.0$$

$$= 4.20 \times 10^{-2} \text{ decimal fraction of baseline capacity/yr}$$

4. Replacement Rate of Obsolete Production Capacity, "P_b"

The variable "P_b" is defined as the average rate at which obsolete production capacity is replaced during the period between the baseline year and 1985.[53]

From Table 2, it is seen that the percent of raw crude that was vacuum distilled from 1965 through 1975 remained fairly constant, averaging 35.54 ± 1.3%.[1-11] This being the case, we have assumed that the rate of obsolescence and replacement for vacuum distillation capacity is proportional to the rate of obsolescence for the total refinery capacity.

Table 13 lists total yearly refinery obsolete capacities from 1966 through 1975. These data are also plotted in Figure 14.[54]

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[54] Refining. Section VIII in: Basic Petroleum Data Book, Petroleum Industry Statistics. American Petroleum Institute, Washington, D.C., October 1975.

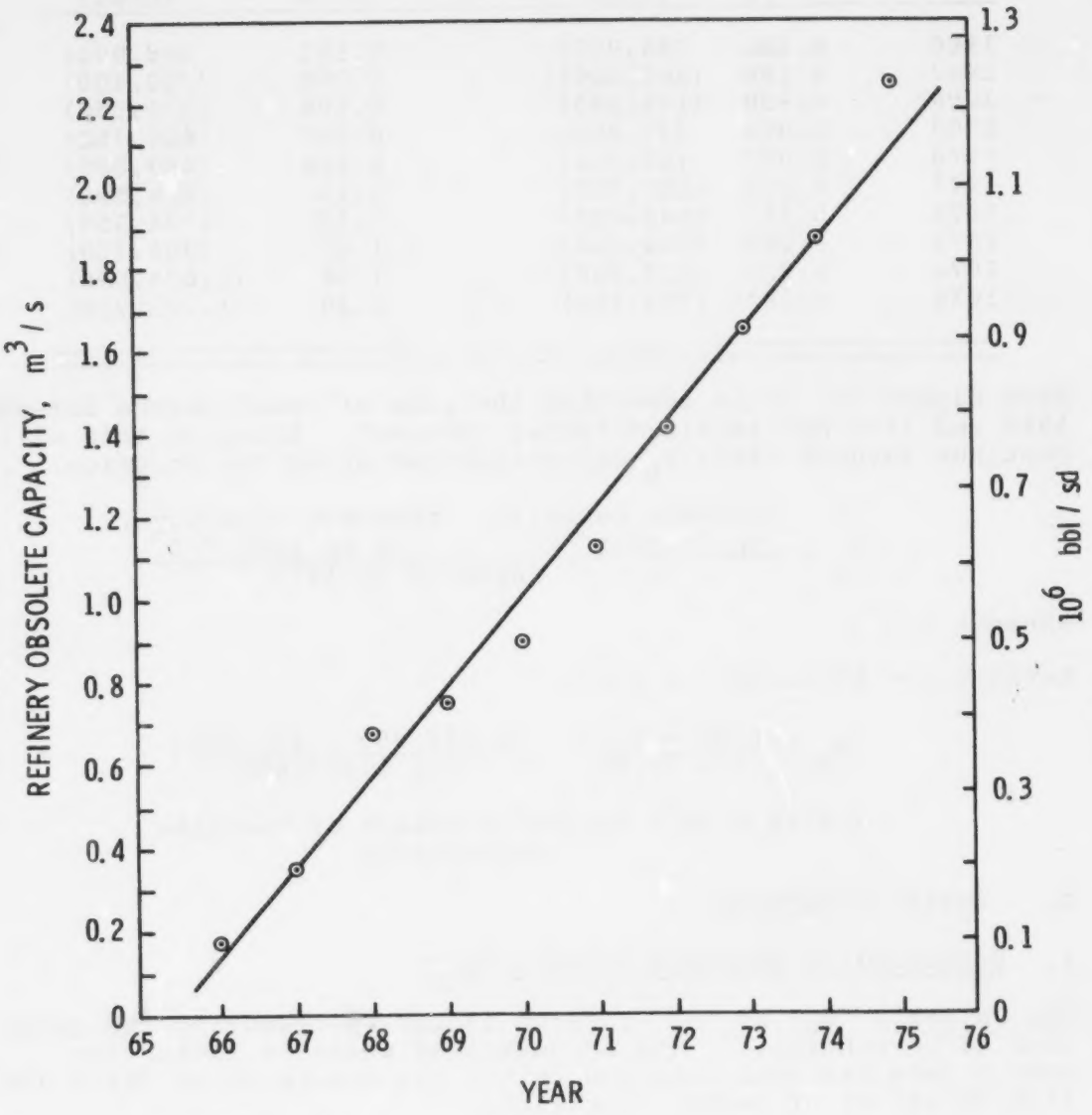

Figure 14. Refinery obsolete capacity, 1965-1975.

TABLE 13. REFINERY OBSOLETE CAPACITY

Year	Inoperable shutdown m^3/s	Inoperable shutdown (b/sd)	Total obsolete capacity since Jan. 1966 m^3/s	Total obsolete capacity since Jan. 1966 (b/sd)
1966	0.181	(98,900)	0.181	(98,900)
1967	0.186	(101,200)	0.368	(200,100)
1968	0.330	(179,450)	0.698	(379,550)
1969	0.068	(37,200)	0.767	(416,750)
1970	0.097	(53,050)	0.864	(469,800)
1971	0.294	(159,750)	1.15	(629,550)
1972	0.267	(145,000)	1.42	(774,550)
1973	0.243	(132,200)	1.67	(906,750)
1974	0.235	(127,900)	1.91	(1,034,650)
1975	0.382	(208,100)	2.29	(1,242,750)

From Figure 14, it is seen that the rate of obsolescence between 1966 and 1975 has remained fairly constant. Assuming this will continue through 1985, P_b was calculated using the equation:

$$P_b = \frac{\text{Obsolete capacity up to year "x"} - \text{obsolete capacity up to year "y"}}{(x - y)\ \text{Capacity in 1975}}$$

where $x > y$

Letting $x = 1974$ and $y = 1967$:

$$P_b = \frac{1.91 - 0.37}{7 \times 10.44} \quad \left(\frac{1{,}034{,}650 - 200{,}100}{7 \times 5{,}672{,}898}\right)$$

$$= 2.10 \times 10^{-2} \text{ decimal fraction of baseline capacity/yr}$$

B. EMISSION FACTORS

1. Uncontrolled Emission Factor, "E_u"

The variable "E_u" is the emission factor representing the condition of no control.[53] The uncontrolled emission factor for vacuum jets has been reported in the literature to be 368.5 g/m^3 (130 $lb/10^3$ b) of vacuum distillate.[41]

2. Controlled Emission Factor, "E_n"

The variable "E_n" is the emission factor representing the condition of the best control applied to new sources.[53] On the basis of the study on control of emissions from vacuum distillation units, Section V, it can be concluded that emissions can be 100% controlled.[42-47] Hence, E_n was given the value of zero.

3. Estimated Allowable Emissions Under 1975 Regulations, "E_s"

The variable "E_s" is the emission factor which represents the 1975 (the baseline year) level of control required under state, local, regional, or federal regulations.[53]

A review of state hydrocarbon emissions indicates that even the best regulations are not comprehensive enough to assure the reduction in emissions from vacuum distillation units that would be possible by use of available control technology. For the purpose of this task, "E_s" has been defined as:

$$E_s = \text{(Uncontrolled emission factor for vacuum jets)} \text{ (fraction of industry not controlling emissions)}$$

$$= E_u \text{ (fraction of industry not controlling emissions)}$$

From data on 102 petroleum refineries processing 7.22 m^3/s (3,923,925 b/sd) of vacuum distillate, it was determined that 17 refineries processing 0.60 m^3/s (326,150 b/sd) of vacuum distillate vented hydrocarbon emissions from vacuum distillation units to the atmosphere.

Assuming these data to be typical of the petroleum refining industry, it can be calculated that 16.7% of the refineries processing 9.3% of the vacuum distillate use no controls on vaccum distillation units.

Therefore,

$$E_s = E_u \ (8.31 \times 10^{-2})$$

$$= 8.31 \times 10^{-2} \ (368.5) \ \frac{g}{m^3} \quad \left(8.31 \times 10^{-2} \ (130) \ \frac{lb}{10^3 \ b}\right)$$

$$= 30.6 \ \frac{g}{m^3} \quad \left(10.8 \ \frac{lb}{10^3 \ b}\right)$$

C. INTERMEDIATE VARIABLES

1. Total Emissions in Baseline Year (1975) Under Baseline Year Regulations, "T_a"

The variable "T_a" is defined as the total emissions in 1975 under current (1975) regulations and can be calculated using the equation:[53]

$$T_a = E_s K A$$

By using the previously defined variables, T_a is calculated as:

$$T_a = 9.62 \text{ Gg/yr } (10{,}622 \text{ tons/yr})$$

2. Total Emissions in 1985 Assuming No Control, "T_u"

The variable "T_u" for 1985 can be calculated suing the equation:[53]

$$T_u = E_u K (A - B) + E_u K (B + C)$$

$$= E_u K [(A - B) + (B + C)]$$

$$= E_u K (A + C)$$

a. Using Simple Growth--
By using the previously defined variables, T_u is calculated as:

$$T_u = 154.90 \text{ Gg/yr } (170{,}949 \text{ tons/yr})$$

b. Using Compound Growth--
By using the previously defined variables, T_u is calculated as:

$$T_u = 174.50 \text{ Gg/yr } (192{,}750 \text{ tons/yr})$$

3. Emissions in 1985 Under Baseline Year Control Regulations, "T_s"

The variable "T_s" for 1985 is calculated by using the equation:

$$T_s = E_s K (A - B) + E_s K (B + C)$$

$$= E_s K [(A - B) + (B + C)]$$

$$= E_s K (A + C)$$

a. Using Simple Growth--
By using the previously defined variables, T_s is calculated as:

$$T_s = 12.87 \text{ Gg/yr } (14{,}202 \text{ tons/yr})$$

b. Using Compound Growth--
By using the previously defined variables, T_s is calculated as:

$$T_s = 14.50 \text{ Gg/yr } (16{,}013 \text{ tons/yr})$$

4. Emissions in 1985 Under New or Revised Standards of Performance, "T_n"

The variable "T_n" for 1985 is calculated by using the equation:[53]

$$T_n = E_s K (A - B) + E_n K (B + C)$$

But, $E_n = 0$

Therefore, $T_n = E_s K (A - B)$

$= 7.61$ Gg/yr (8,390 tons/yr)

5. Production Capacity from Construction and Modification to Replace Obsolete Facilities, "B"

Assuming simple growth, the variable "B" can be calculated using the equation:

$$B = iAP_b$$

where i = the number of years

$$B = 2.19 \frac{m^3}{s} \quad \left(1{,}911{,}765 \frac{b}{sd}\right)$$

6. Production Capacity from Construction and Modification to Increase Output Above Baseline Year Capacity, "C"

a. Using Simple Growth--
Assuming simple growth, the variable "C" can be calculated using the equation:[53]

$$Ca = iAP_{ca}$$

where i = the number of years

$$Ca = 3.52 \frac{m^3}{s} \quad \left(1{,}911{,}765 \frac{b}{sd}\right)$$

b. Using Compound Growth--
Assuming compound growth, the variable "C" can be calculated using the equation:

$$Cb = A [(1 + P_{cb})^i - 1]$$

where i = the number of years

$$Cb = 5.3 \frac{m^3}{s} \quad \left(2{,}879{,}053 \frac{b}{sd}\right)$$

7. Impact

The additonal control potential, or impact, of new source performance standards is expressed using simple and compound growth.[54]

a. Using Simple Growth--

$T_s - T_n$ = (12.87 - 7.61) Gg/yr [(14,202 - 8,390) tons/yr]

= 5.26 Gg/yr (5,812 tons/yr)

b. Using Compound Growth--

$T_s - T_n$ = (14.50 - 7.61) Gg/yr [(16,013 - 8,390) tons/yr]

= 6.89 Gg/yr (7,623 tons/yr)

Figure 15 is a graphical representation of the growth rate and rate of obsolescence from baseline year 1975 to the year 1985.

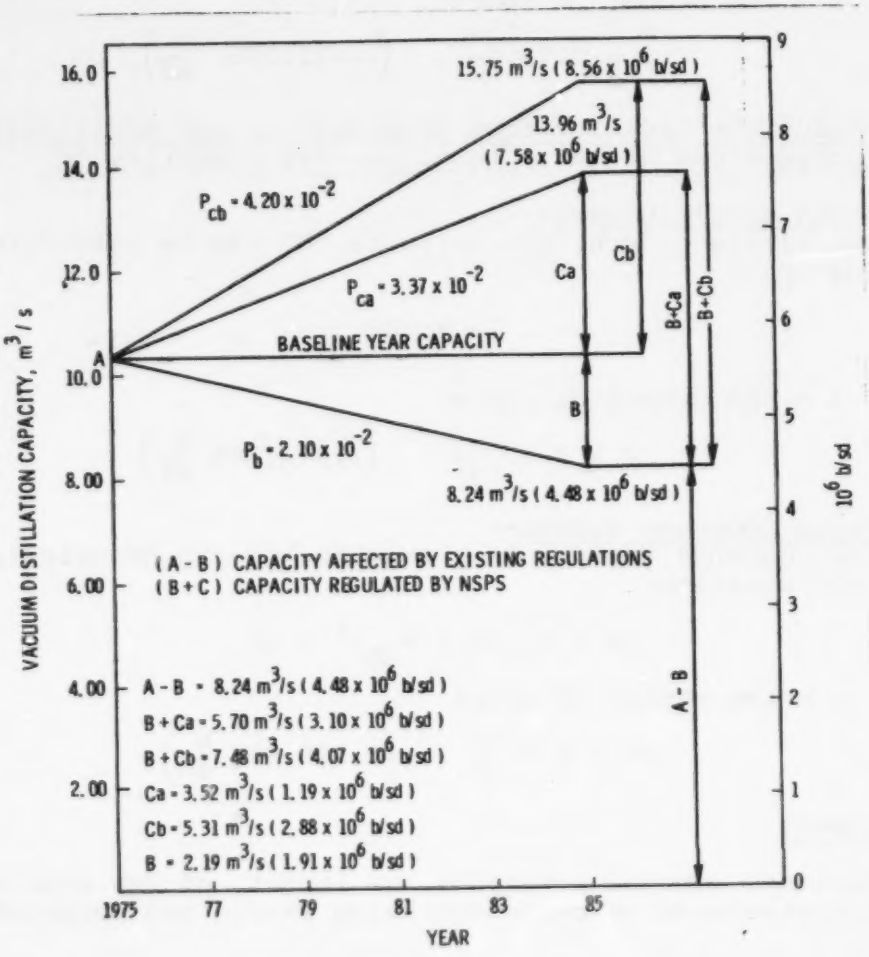

Figure 15. Applicability of NSPS to construction and modification.

Table 14 is a summary of factors used in the calculations. Table 15 summarizes the total national emission reduction that would occur annually 10 years from the date the standard would be in effect.

TABLE 14. SUMMARY OF INPUT/OUTPUT VARIABLES FOR VACUUM DISTILLATION

Normal fractional utilization factor	K	0.95
Emission rate, g/m^3 (lb/10^3 b)	E_u	368.5 (130)
	E_s	30.6 (10.8)
	E_n	0 (0)
Growth rates, decimal/yr	P_c (SG)[a]	3.37×10^{-2}
	P_c (CG)[b]	4.19×10^{-2}
	P_b	2.10×10^{-2}
Industrial capacity, m^3/s (b/sd)	A (1975)	10.44 (5,672,893)
	B (1985)	2.19 (1,192,213)
	C (1985) (SG)[a]	3.52 (1,911,765)
	(CG)[b]	5.30 (2,879,053)
Emissions, Gg/yr (tons/yr)	T	9.62 (10,622)
	T_u (SG)[a]	154.90 (170,949)
	T_u (CG)[b]	174.50 (192,750)
	T_s (SG)[a]	12.87 (14,202)
	T_s (CG)[b]	14.50 (16,013)
	T_n	7.61 (8,390)
Impact, g/s (tons/yr)	$T_s - T_n$ (SG)[a]	5.26 (5,812)
	$T_s - T_n$ (CG)[b]	6.89 (7,623)

[a] SG = Simple industry growth.

[b] CG = Compound industry growth.

TABLE 15. NATIONAL EMISSION REDUCTION IN 1985

Control technique	Vapor recovery or disposal	
	Gg/yr	(tons/yr)
Emission rate with best system	0	(0)
Current emission rate (1985)	(SG)[a] 12.87	(14,202)
	(CG)[b] 14.50	(16,013)
Emission reductions (1985)	(SG)[a] 5.26	(5,800)
	(CG)[b] 6.89	(7,623)

[a]SG = Simple industry growth.

[b]CG = Compound industry growth.

SECTION VIII

MODIFICATION AND RECONSTRUCTION

In the petroleum refining industry, the vacuum distillation process can be modified or reconstructed for the purpose of increasing capacity and/or installing systems for the reduction of atmospheric and/or water pollution.[44,55-58] The best applicable systems of emission reduction are discussed in Section V.

Modification and reconstruction of vacuum distillation processes within the petroleum industry would affect atmospheric emissions only if capacities were increased without the installation of applicable systems of emission reduction. From conversations with petroleum industry personnel and equipment manufacturers, it appears that all newer refineries install systems to reduce both air and water pollution.[44-46,55-59,71,72] Control systems are also usually installed, for safety and economic reasons, when existing vacuum units are modified or reconstructed.

The capacity of a vacuum distillation unit can be increased in a number of ways, including:

- Utilizing full design capacity of the vacuum still
- Installing a second vacuum unit in parallel
- Constructing a second, parallel refinery

A. UTILIZING FULL CAPACITY OF THE VACUUM STILL

Refinery equipment is usually designed to operate below maximum capacity so that there remains room for expansion. Therefore, the production capacity of the vacuum distillation unit can be increased by simply replacing other process equipment that is creating bottlenecks upstream from the vacuum unit.

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[55]Personal communication with P. Tranquill, Sohio Oil Refinery, Lima, Ohio, 24 June 1976.

[56]Personal communication with J. Gurawitz, Standard Oil Company, Chicago, Illinois, 2 July 1976.

[57]Personal communication with Mr. Reed, Edgington Oil Company, Long Beach, California, 2 July 1976.

[58]Personal communication with Mr. Brooks, Texaco Oil Company, Westville, New Jersey, 2 July 1976.

Table 16 lists the atmospheric and vacuum distillation capacities from 1965 to 1975 for The Standard Oil Company of Kentucky located in Pascagoula, Mississippi.[59] The table shows that in 1970 the capacity of the vacuum distillation unit increased by 0.125 m^3/s (68,000 b/sd). This is a typical example of increasing vacuum unit capacity by replacing process equipment upstream. In this case, the refinery added a new atmospheric crude distillation unit, replaced heat exchangers, and modified furnaces, pumps, etc.[59] The design capacity of the vacuum still remained unchanged.

TABLE 16. ATMOSPHERIC AND VACUUM DISTILLATION CAPACITY FOR STANDARD OIL COMPANY OF KENTUCKY, 1965-1975[1-11,60-70]

	Capacity			
	Atmospheric distillation		Vacuum distillation	
Year	m^3/s	(b/sd)	m^3/s	(b/sd)
1975	0.543	(295,000)	0.272	(148,000)
1974	0.465	(253,000)	0.272	(148,000)
1973	0.465	(253,000)	0.272	(148,000)
1972	0.515	(280,000)	0.257	(140,000)
1971	0.534	(290,000)	0.257	(140,000)
1970	0.534	(290,000)	0.250	(136,000)
1969	0.267	(145,000)	0.125	(68,000)
1968	0.267	(145,000)	0.125	(68,000)
1967	0.267	(145,000)	0.125	(68,000)
1966	0.239	(130,000)	0.119	(65,000)
1965	0.239	(130,000)	0.119	(65,000)

[59]Personal communication with J. Sullivan, Standard Oil Company of Kentucky, Pascagoula, Mississippi, 1 July 1976.

[60]World-Wide HPI Construction Boxscore. Hydrocarbon Processing, 54(10, Section 2):3-16, 1975.

[61]World-Wide HPI Construction Boxscore. Hydrocarbon Processing, 53(10, Section 2):3-12, 1974.

[62]World-Wide HPI Construction Boxscore. Hydrocarbon Processing, 52(10, Section 2):3-10, 1973.

[63]World-Wide HPI Construction Boxscore. Hydrocarbon Processing, 51(10, Section 2):3-10, 1972.

[64]World-Wide HPI Construction Boxscore. Hydrocarbon Processing, 50(10, Section 2):7-15, 1971.

[65]World-Wide HPI Construction Boxscore. Hydrocarbon Processing, 49(10, Section 2):CR-5 to CR-18, 1970.

Table 17[1-11,60-70] lists the atmospheric and vacuum distillation capacities from 1965 to 1975 for the Amoco Oil Company located in Whiting, Indiana. From Table 17 it is seen that the vacuum unit capacity was increased a number of times. In 1968, it increased by 0.011 m^3/s (6,000 b/sd) and in 1973 it increased by 0.43 m^3/s (23,000 b/sd). These increases are typical examples of increasing the capacity of the vacuum unit by modifying or replacing "bottleneck" or process equipment downstream.[71] Again, the design capacity of the vacuum unit was not changed.

TABLE 17. ATMOSPHERIC AND VACUUM DISTILLATION CAPACITY FOR THE AMOCO OIL COMPANY, 1965-1975[1-11,60-70]

	Capacity			
	Atmospheric distillation		Vacuum distillation	
Year	m^3/s	(b/sd)	m^3/s	(b/sd)
1975	0.662	(360,000)	0.307	(167,000)
1974	0.662	(360,000)	0.307	(167,000)
1973	0.579	(315,000)	0.258	(140,000)
1972	0.561	(305,000)	0.215	(117,000)
1971	0.485	(264,000)	0.235	(128,000)
1970	0.557	(303,000)	0.235	(128,000)
1969	0.542	(295,000)	0.235	(128,000)
1968	0.546	(297,000)	0.235	(128,000)
1967	0.443	(241,000)	0.224	(122,000)
1966	0.421	(229,000)	0.224	(122,000)
1965	0.381	(207,000)	0.224	(122,000)

[66]HPI Construction Boxscore. Hydrocarbon Processing, 48(10, Section 2): CR-13 to CR-25, 1969.

[67]HPI Construction Boxscore. Hydrocarbon Processing, 46(9, Section 2):CR-9 to CR-28, 1968.

[68]HPI Construction Boxscore. Hydrocarbon Processing, 46(9, Section 2):56-68, 1967.

[69]HPI Construction Boxscore. Hydrocarbon Processing, 45(9, Section 2):75-88, 1966.

[70]HPI Construction Boxscore. Hydrocarbon Processing, 44(9, Section 2):56-68, 1965.

[71]Personal communication with Mr. Harbison, Amoco Oil Company, Whiting, Indiana, 1 July 1976.

B. INSTALLING A SECOND VACUUM UNIT IN PARALLEL

When the bottlenecks downstream from the vacuum still are removed, the vacuum distillation unit itself eventually becomes a bottleneck. Possible solutions are to modify or replace the vacuum unit, or install another unit in parallel. Replacing only the vacuum unit is expensive and is very seldom practiced.[72]

Table 18 lists the atmospheric and vacuum distillation capacities from 1965 to 1975 for the Cities Service Oil Company located in Lake Charles, Louisiana.[72] As shown in the table, in 1973 the capacity increased from 0.079 m^3/s (43,000 b/sd) to 0.110 m^3/s (60,000 b/sd). This is a typical example of increasing vacuum distillation capacity by installing a new vacuum unit in parallel to the existing one and then splitting the topped crude from the atmospheric distillation unit for feed to the two vacuum units.[72]

TABLE 18. ATMOSPHERIC AND VACUUM DISTILLATION CAPACITY FOR CITIES SERVICE OIL COMPANY, 1965-1975[1-11,60-70]

	Capacity			
	Atmospheric distillation		Vacuum distillation	
Year	m^3/s	(b/sd)	m^3/s	(b/sd)
1975	0.515	(280,000)	0.152	(83,000)
1974	0.515	(280,000)	0.152	(83,000)
1973	0.515	(280,000)	0.110	(60,000)
1972	0.450	(245,000)	0.079	(43,000)
1971	0.423	(230,000)	0.079	(43,000)
1970	0.423	(230,000)	0.079	(43,000)
1969	0.388	(211,000)	0.079	(43,000)
1968	0.349	(190,000)	0.077	(42,000)
1967	0.349	(190,000)	0.077	(42,000)
1966	0.349	(190,000)	0.077	(42,000)
1965	0.349	(190,000)	0.077	(42,000)

C. CONSTRUCTING A SECOND COMPLETE REFINERY

Occasionally a refiner may feel the need to expand production, but it may not be economically practical to replace or modify process equipment within the existing refinery. If sufficient space exists on site, a new refinery may be constructed to take advantage of the existing support facilities. Typical example of such a case is the Sohio refinery in Lima, Ohio.

[72]Personal communication with Mr. Murphy, Cities Service Oil Company, Lake Charles, Louisiana, 1 July 1976.

Table 19 lists the atmospheric and vacuum distillation capacities from 1965 to 1975 for this refinery,[55] and shows that in 1970 the capacity of its vacuum distillation unit was increased from 0.020 m^3/s (11,000 b/sd) to 0.087 m^3/s (47,500 b/sd). This change in capacity occurred when a new refinery, with a vacuum distillation capacity of approximately 0.083 m^3/s (45,000 b/sd), went on stream near the existing refinery within the same battery limits.[55]

TABLE 19. ATMOSPHERIC AND VACUUM DISTILLATION CAPACITY FOR THE SOHIO OIL COMPANY, 1965-1975[1-11,60-70]

	Capacity			
	Atmospheric distillation		Vacuum distillation	
Year	m^3/s	(b/sd)	m^3/s	(b/sd)
1975	0.325	(177,000)	0.093	(51,000)
1974	0.325	(177,000)	0.093	(51,000)
1973	0.322	(175,000)	0.093	(51,000)
1972	0.284	(154,500)	0.093	(51,000)
1971	0.265	(144,000)	0.087	(47,500)
1970	0.265	(144,000)	0.087	(47,500)
1969	0.109	(59,600)	0.020	(11,000)
1968	0.109	(59,600)	0.020	(11,000)
1967	0.105	(57,500)	0.020	(11,000)
1966	0.104	(56,500)	0.020	(11,000)
1965	0.092	(50,000)	0.020	(11,000)

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